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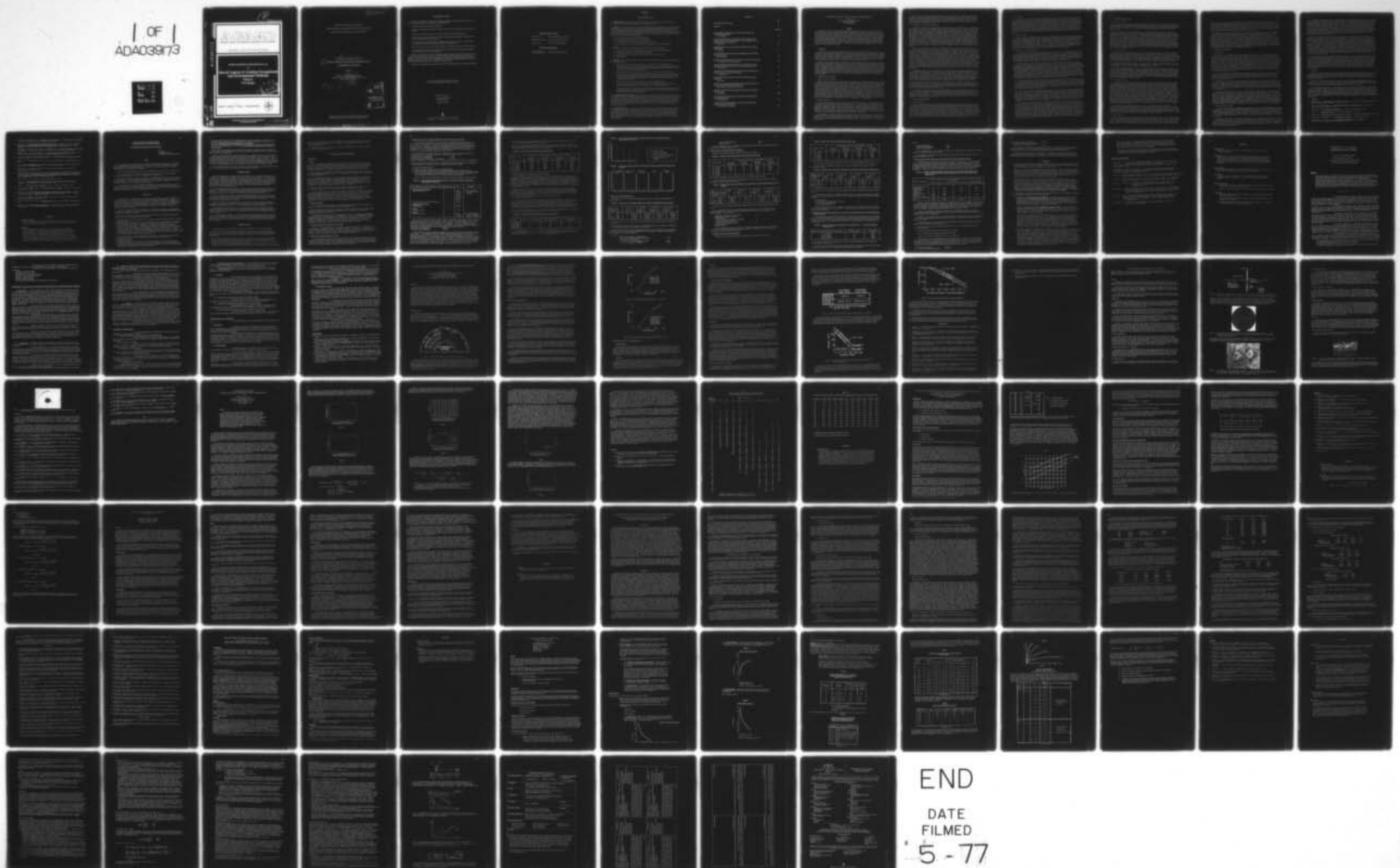

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Edited by

M.S.Hughes



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# SPECIAL ASPECTS OF AVIATION OCCUPATIONAL AND ENVIRONMENTAL MEDICINE


Edited by

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Wing Commander M.S. Hughes, RAF
RAF Institute of Aviation Medicine, Farnborough
Hants, United Kingdom


11 Feb 77 12 91p.




Papers presented at the Aerospace Medical Panel Specialists' Meeting held in Athens, Greece, 20–24 September 1976.


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## AEROSPACE MEDICAL PANEL

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|---|---|---|
| Host Coordinator and Program Organizer | : | Colonel C.E.Giannopoulos, HAF |

## PREFACE

by

Wing Cdr. M.S.Hughes, RAF

1. **INTRODUCTION.** The 33rd Aerospace Medical Panel Meeting was held in Athens, Greece during the 20–24 September 1976, of which B was one of three Sessions constituting the meeting.

2. **THEME.** The committee on Special Clinical and Physiological Problems in Military Aviation have long felt that the aviation environment is of growing concern in respect of occupational health hazards facing not only Air Crew but Air Traffic Controllers, Radar Operators and Ground Support Personnel, whilst populations living near airports are increasingly affected by noise and atmospheric pollution. It was decided therefore, that it be recommended to the Panel that a session be held to discuss the occupational environment of all involved in aviation, and in particular it was felt that there was a need to air the problems associated with:

(a) the creation and running of Occupational Health Services

(b) the identification and minimisation of dangerous procedures

(c) the setting of limits to exposures encountered during these procedures

(d) the psychological stresses associated with aviation, in particular those of Air Traffic Controllers.

3. **SCOPE.** As a consequence the Panel issued invitations for papers on the following subjects.

(a) Medical, psychiatric and psychological problems of Air Traffic Controllers and Radar Operators.

(b) Atmospheric (including noise) pollution by aircraft operations.

(c) Industrial hazards, the toxicology and pathology of propellants and other chemicals.

(d) Missile Operations.

4. **FORMAT.** Twelve papers were chosen and were arranged in groups dealing with their common aspects. The groups were sub-titled as follows:

(a) *Medical, Psychiatric and Psychological Problems of Air Traffic Controllers and Radar Operators.*

Three papers were read in this group and a profitable in depth analysis of the Occupational Health Problems of Air Traffic Controllers was achieved. Hopkin (UK) also outlined problems that may well have to be faced in the near future, as a result of developing technology.

(b) *Monitoring, Measurement and Assessment of Potential Hazards Associated with Aircraft Operations.*

The intention and scope of this sub group was to identify, quantify and arrive at estimates as to the magnitude of some of the more specialised hazards associated with aircraft operations, and offer recommendations on their monitoring and safety limits. The dissemination of information from experts in their field was clearly welcomed by the member nations.

(c) *Industrial Hazards and their Control Associated with Aircraft and Missile Operations.*

Here it was intended to air authoritative opinions on the creation of Health Programmes, whilst also concentrating on the toxicology of hydrazine, a complex but an increasingly common hazard.

Recent developments in military tactics have also demanded the operation of aircraft from hard shelters. The environmental hazards associated with these operations was dealt with in considerable depth and much interest was generated by the U.K. experience in this field.

5. **SUMMARY AND CONCLUSIONS.** Session B consisted of an in-depth analysis of the working environment of those employed in the aviation field. It identified many of the current health hazards, and pinpointed many that workers may be exposed to in the future. Recommendations were made as to their avoidance and control, and it was felt that the session resulted in meaningful and worthwhile advice being made to the panel and through it to doctors responsible for the health of employees in this industry. In such a vast field much was left undone and unsaid, but insofar as was possible to do so in one and a half days much was done and said, and in this respect it is believed the session was very successful and worthwhile.

6. **RECOMMENDATIONS.** As further experience is gained in Hard Shelter Operations I think that regular updating sessions should be held on their environmental aspects. It seems obvious that the more we travel along this road the more problems we shall find, and to prevent undue repetition of work and mistakes with consequent expense regular exchange of information would be advantageous. Perhaps at some time in the future an AGARDograph might help. The same philosophy holds true for the field of toxicology, and what was so successfully done for hydrazine at this meeting should be done for other toxicological hazards as each is identified and preferably before they are introduced into widespread use.

# CONTENTS

# PSYCHOLOGICAL PROBLEMS OF AIR TRAFFIC CONTROLLERS AND RADAR OPERATORS

V. David Hopkin
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United Kingdom

## SUMMARY

Potential solutions to some of the psychological problems traditionally associated with air traffic control and radar operators have become available with the advent of secondary radar and of advances in display technology. Greater flexibility in workspace design can remove many of the main sources of visual and postural difficulties. Recently the effects of stress on efficiency and well-being have been the subject of much keen debate and of some research, particularly in air traffic control. Some of the psychological problems associated with boredom are equally serious, but comparatively neglected. When automation in the form of computer assistance is applied to decision making and problem solving, its implications extend beyond system performance and efficiency to influence job satisfaction, professional pride, opportunities to acquire and use skills, and the integration of the roles of man and machine. These less manifest effects of automation are the source of numerous current and future psychological problems for air traffic controllers and radar operators.

## 1. INTRODUCTION

In the past, some recalcitrant psychological problems and environmental health hazards have been associated with the tasks and the working conditions of air traffic controllers and of radar operators. The main impetus for research seeking to remove these problems and hazards came from the operational need to maintain or restore system efficiency. Sometimes it was presumed, on insufficient evidence, that all the information necessary to reach required operational standards had been provided in usable form. The success or failure of any changes in air traffic controllers' or radar operators' tasks was judged according to achieved performance, neglecting incidental effects on well-being, job satisfaction or effort.

Because of the serious operational consequences of poor performance of air traffic control or radar operating tasks, from whatever cause, much effort was devoted to providing work environments which fostered efficient task performance. Radar displays, particularly in conjunction with other displays in the console or with wall-mounted displays, created many problems in workspace design, the most serious of which were visual. Attempts were made to formulate general principles for the design of efficient workspaces. Numerous studies of specific environments sought either to improve performance in future systems, or to achieve more acceptable performance in existing systems if the attained efficiency had manifestly failed to match operational requirements. These principles and findings have been incorporated in specific(1) and general(2) handbook recommendations, and many of the ambitious research programmes from which they were derived have been described(3).

## 2. TRADITIONAL VISUAL PROBLEMS

### 2.1 Quality of Radar Information

Early studies were concerned with difficulties in discriminating or interpreting the contents of radar displays(4). The displayed information was often of poor quality, near the visual threshold, viewed against a cluttered background, and subject to fading and uncertainty. The radar tracker had to find, identify and follow the blips which constituted the track of an aircraft or target. Sometimes the man was expected not only to detect the presence of a radar track but also to discriminate it from others and make accurate intuitive speculations about what it might represent. While the successful performance of such a task was operationally desirable, the requisite information was not always present. When it was, its quality might be so poor that great skill, experience or flair were required to interpret it with consistent success. In some circumstances it was very difficult to verify whether an interpretation was correct or not. Attributes of the blip, such as its size, shape, visual texture, relative movement and persistence, were used by the experienced radar operator to decide whether a genuine track was present and to suggest what it might represent. With such a display, any small departure from the visually optimum environment, or a marginal degradation of the display itself, could render much of the information on it unintelligible.

### 2.2 Ambient Illumination

It was therefore imperative that any information which could be sensed by the system and appear on the display should not then be lost because the man could not see it. The type and level of ambient illumination had to be chosen carefully to optimise the visibility of the radar information. Amber tubes had white-minus-amber lighting for example, and other types of ambient illumination, such as broad blue band, were evaluated in relation to specific display characteristics(5). It was acknowledged that the radar picture might need adjustment from time to time, and therefore the operator was provided with a facility to vary the brightness of his radar display, although it was never proved that he was capable of choosing the operationally most efficient brightness setting as distinct from the one he liked best.

The degradation of displayed information by reflections and glares on the tube face was studied, and precautions were taken to minimise the unwanted scattering of light. It proved difficult to position light fitments in a large room containing numerous radar displays, without incurring reflections or glare somewhere. Elaborate cowlings and controls for light fitments were often introduced to try and circumvent this difficulty(6).

In many early radar rooms the lighting levels were so low that operators on entering the room had to wait until they had become sufficiently dark adapted to the environment to go to their workplaces without tripping over furniture or bumping into others. In circumstances when any departure from optimum viewing conditions could render displays useless, changes which were desirable for the operators' comfort or well-being, but which would make their tasks impossible, could not be entertained because they would lead to gross impairment of operational efficiency.

2.3 Compatibility of Radar and Other Displays

The relationship between the radar display and other displays in the same workspace led to difficulties. One problem was to ensure that information on other displays in the same console or suite as the radar display remained visible under the low ambient lighting levels entailed by the radar. Beyond each man's workspace, undesirable pools of darkness or brightness within the visual environment could occur, associated with different lighting requirements for different displays. The employment of colour coding of information was restricted by the low lighting levels and often by the need to use coloured ambient lighting. Some improvements to the visual environment were made by using relatively neutral or unsaturated colours with matt surfaces, to reduce unwanted glare, reflections and light scattering. Certain traditional features of air traffic control and radar working environments continued to appear although they were not appropriate, and probably never had been. For example, whereas the presence of radar displays might make dark ceilings and dark walls essential, the almost universal adoption of dark flooring implied a blinkered approach to optimising the workspace and to appraising the factors which could be modified. Even under present conditions light coloured flooring in rooms with low illumination enables furniture to be more readily seen, and the level of ambient illumination can generally be raised somewhat in this way without significant visual penalty.

The use of radar displays in conjunction with large wall-mounted displays has been a prolific source of visual problems in the past. At one time, wall displays were almost universal in air defence and air traffic control environments, and they are still very common in the former. A task analysis does not always prove the need for general wall-mounted displays, and the reasons advanced in their favour are not always convincing. The information on them is normally of limited use to individual controllers or operators since each man requires for his own job more detailed information than they give. While it is not contended that general displays are superfluous, the way in which they are actually used, rather than the ostensible reasons for their presence, should be made clear. In many air defence or air traffic control environments a summary of the current situation helps to provide everyone with some knowledge of the results of their efforts and of what is happening. A wall-mounted general situation display may serve this purpose well, and may be suitable for briefing and for various command decisions, though it should not be designed solely to meet the needs of the most senior man present, which are usually better served by an individual display. It may also be useful as a simplified and readily intelligible summary for visitors who are not concerned with the fine detail of the system and may have neither the time nor the inclination to understand it fully; but there is great reluctance to admit openly that a main justification for its existence may be its value as a summary for visitors.

Wall-mounted displays in radar environments pose in more acute form all the visual problems associated with displays within the console. If possible, the man's radar and other individual displays should be matched fairly closely in brightness with the wall display, particularly if he frequently has to cross refer between them. Visual difficulties may be encountered with tasks requiring this cross referal constantly, and task designs should minimise the need for it. The difficulties are aggravated if frequent visual accommodation changes associated with the different visual distances of individual and wall-mounted displays are accompanied by changes in pupil size because the display sources differ substantially in brightness levels. General situation displays are normally far enough from the man to appear at visual infinity.

Wall-mounted displays often have specialised illumination, such as ultra-violet lighting or back or forward projection. In some current systems, methods for updating this information have been little influenced by modern technology. It is still possible to find wall displays which are amended manually from the rear by writing a mirror image of the characters. In such displays, viewing panels must be transparent, and this can aggravate glare and reflectance problems.

The reason for recounting these traditional visual problems is that at present many radar operators still work in these conditions, with a radar picture containing information near the visual threshold, with low levels of ambient lighting of a spectrum which is compatible with the radar display but not with other displays, and with combinations of near and far information displays which entail frequent head and eye movements, and reaccommodation. Such working conditions have caused psychological and occupational health problems in the past, and continue to do so.

3. OTHER TRADITIONAL PROBLEMS

3.1 Knowledge of Results

Another long-standing psychological problem associated with ground control systems, and particularly with radar operators, has been the provision of adequate knowledge of results to show the operator the consequences of his actions for the system as a whole, and thereby enable him to learn to improve his performance. Operators trained to follow standard instructions may have no clear idea of their true role within the system, or of the efficacy of what they are doing. If an operator has insufficient knowledge of results, his tasks, which may already tend to be dull and tedious, can become even more so. Some tasks, particularly those related to vigilance(7) and visual search(8), may be of a kind which man does inefficiently but which have to be done manually because they cannot be automated. Even the most experienced, skilled and well-motivated man cannot perform, day after day, a routine vigilance task on a radar display with a consistently high level of success, particularly if he cannot tell whether he is doing the task well or not.

3.2 Watch Lengths

The efficiency of performing vigilance and search tasks decreases during a period of continuous working, although this effect has been more clearly established in the laboratory than under operational conditions and may to some extent be an artifact of laboratory experiments. In practice it is acknowledged that the man should not do such tasks continuously for long without a break. It is difficult to make firm recommendations on the spacing, length and nature of breaks, since characteristics of the task, of the individual man, of the working environment and of the equipment are all relevant, but continuous watch periods of two hours are normally too long to maintain efficiency. For certain radar tasks, thirty or forty minutes is long enough to work without a break, and even during such short periods the level of proficiency may gradually decrease, perhaps with a late improvement in performance if the man knows that a break is nearly due[9]. In extreme cases the period required to become fully dark adapted may approach the duration of each watch period.

3.3 Postural Problems

In most ground control systems, tasks are designed to be performed by teams. Controllers and operators liaise closely with their colleagues, often to the extent of sharing displays or other facilities. There are difficulties in designing furniture and in locating displays and controls within it to meet known ergonomic requirements for individual operators[10]. Tasks may require more displays and facilities than can be accommodated within the operator's immediate field of view or within easy reach. He may have to stretch or lean in order to see information or to reach controls. The most serious postural problems are associated with shared horizontal information displays. There is inadequate room for legs or knees under these displays, and some operators therefore have to sit alongside them and lean sideways across them[11]. The frequent adoption of such postures reveals or aggravates any incipient postural weaknesses.

3.4 Effects of New Display Technology

As air traffic control and air defence systems have come to rely more on centralised computers and to incorporate new display principles, many of the causes of design problems in such systems which paid little heed to operators' needs are no longer present. While it is potentially misleading to imply that displays are suitable for normal daylight viewing by describing them as daylight displays or bright displays, nevertheless higher and more acceptable levels of ambient lighting can now be introduced into the workspace. The arguments against daylight at workspaces in ground control systems now concern its variability as much as its brightness, with the need to maintain satisfactory lighting during exterior darkness.

Problems arose in the past by giving radar operators a task which could not be done well because of limitations in human capabilities, by ensuring poor motivation because the task was dull and knowledge of results could not be provided, and by requiring the task to be done in a dark, tiring and perhaps depressing environment to which operators had to adapt. For many tasks, primary radar can now be replaced by processed radar presenting computer generated information derived synthetically from primary sources. All such information can be displayed in a form which is clear and easy to interpret. Deficiencies in the portrayal of information originate in faults in the display specification, which can be remedied, and not in inadequate data sensing, which could not be circumvented. Information is now more legible because modern displays with a rapid decay rate and frequently refreshed picture have replaced displays with a low decay rate and consequent smearing of dynamic information. Several recent advances in display technology permit all the information presented to be bright, clear, stable and with good background contrast. These developments facilitate the interpretation of display content and allow higher levels of ambient illumination.

As a result workspaces can now be designed to meet the needs of the man as well as operational requirements. Workspaces for many air traffic controllers and radar operators can be well lit so that they can see to read and write without difficulty. While problems are still met in matching the lighting of wall-mounted and individual displays and of radar and adjacent non-radar displays; satisfactory solutions to such problems can now be devised. Since the working environment is clearly visible, materials and colours which blend and look efficient and attractive should be chosen for it. Controllers and operators can go straight to their workplaces without any period of dark adaptation.

These advances in display technology provide potential solutions for some of the commonest problems in ground control systems. Until new equipment has replaced the old, those benefits remain potential rather than actual. However in the long term the seriousness and frequency of the traditional problems associated with radar rooms should gradually decrease until they become uncommon. Meanwhile the requirements remain to equate local and wall-mounted displays for brightness, and to minimise the need to cross refer between them, by employing appropriate task designs in which computer storage and individual call-down facilities enable the man to select for presentation on his own display all the information he needs for his task, including a summary of the general situation if this is pertinent to his task or to his knowledge of results.

Technological advances may also help to alleviate postural problems. Many previous faults could be attributed to inadequate task design, such as the need to stretch up, reach over-head, stretch across an adjacent operator, or sit sideways with shoulders hunched in order to see an essential display or to bring a control within reach. Nevertheless inherent equipment limitations sometimes prevented the formulation of any adequate task design. Current and future systems place more emphasis on inter-console marking, on actively retrieving required information from the system, and on transmitting information via keyboard and the computer rather than verbally. This leads to greater autonomy at individual work positions, and to indirect rather than direct consultations between team members. Tasks can now therefore be designed for individuals rather than for teams, and workspace designs optimised for individual instead of team functions. With increased individual autonomy the incidence of postural difficulties should decline. The expected trend is towards vertical rather than horizontal displays. However, postural difficulties may persist for some years, as long as the equipment configurations which give rise to them remain in operational use.



3) le groupe des élèves et stagiaires (3,864 %);
4) le personnel administratif et technique

## 4. THE CURRENT PROBLEM OF STRESS

### 4.1 Stress as a Stimulus

In air traffic control much attention has recently been paid to stress. It is now accepted that stress is a problem in air traffic control, and the main emphasis is on methods of quantifying it and alleviating it[12,13]. There is no agreement on a definition of stress or even on the sort of concepts which should be used to describe it. The word 'stress' is used with two distinct meanings; as stimulus (cause) and as response (effect).

Stress as a stimulus is a very broad concept. It may refer to almost any aspect of the physical environment, the tasks, or working conditions which in some way departs from the optimum. Numerous kinds of measurement may purport to assess stress, including performance and systems measures, physiological and biochemical indices, and subjective reports. Stresses may be classified as physical environmental stresses (noise, cold, etc), load and speed stresses (having too much work to do or too little time to do it), task induced stresses (responsibility for safety, etc), social stresses (ability to work amicably with others), and stresses associated with conditions of employment (management quality, morale, shift work, off duty facilities, job satisfaction, etc). Additionally, factors not directly associated with the work, such as domestic or financial crises, may constitute stresses which affect the man at work, mentally, behaviourally and physiologically. Stress must therefore be treated partly in general terms, insofar as, for example, all loud noise may be a stress. It must also be treated in individual terms because the individual's receptivity, his state of adaptation and the other stresses to which he is being concurrently subjected, all mediate the severity of a given stress.

### 4.2 Stress as a Response

The concept of stress is also employed to refer to the individual's response to stress as a stimulus. In this sense, stress is sometimes called strain, or distress. Stress as an individual response may be measured behaviourally, subjectively, physiologically or biochemically. Stress is not necessarily unpleasant and people may seek to generate it in their leisure activities. Its importance for air traffic controllers or radar operators relates both to its associated physiological and biochemical changes and also to its effects on performance and system capacity, often by reducing the workload the man can successfully undertake. The nature of the individual's response to, and tolerance of, stress is probably linked to his personality.

Ambiguities about the concept of stress can be illustrated by trying to define its opposite. In one sense the opposite of stress may be boredom. In another sense, its opposite may be having an optimum amount of interesting work to do at one's own pace: boredom may then be a stress.

The number of published papers on stress in air traffic control is now very large, especially in controllers' own professional literature. Although some papers report scientific findings or statistical relationships, many are mainly descriptive, or list postulated categories of stress. The findings of studies on stress have often been used not to determine tolerable levels or to reduce it, but to claim better working conditions such as earlier retirement, shorter working hours and rearrangement of shifts. While these may be worthy aims the evidence to support such claims is not strong when derived solely from findings about stress. Unwarranted preconceptions on the causes of stress in the individual have sometimes had undue influence on the interpretation of findings about it.

### 4.3 Inconsistent Findings

A characteristic of studies on stress in air traffic control is that findings from different countries do not fully agree. Even with simple assessments, such as comparing the incidence of a few psychosomatic illnesses among controllers and other groups, the results do not tally, the problem being apparently more severe in the United States than in the United Kingdom for example. There is no shortage of hypotheses to explain this finding, but the evidence required to establish which are correct does not exist. Although controllers in both countries nominally do the same task, in fact the air traffic control procedures, the divisions of airspace, the traffic densities and patterns, and the nature of the air traffic all differ. In the United States there is far more general aviation traffic, often associated with less experienced pilots and with fewer navigation aids in the aircraft. Controllers in the two countries are not drawn from equivalent statistical populations, and are not selected in the same way. Their training is different, and also their experience since policies about moving controllers to other regions and other kinds of air traffic control are not the same. There are differences in work/rest cycles and in hours of work[14]. Conditions of employment, standards of living, life styles, and quality of management may also differ. Further relevant factors could be postulated, such as the status of air traffic control as a profession, the extent of the individual's identification with his profession and the intrinsic interest of the job. Any satisfactory explanation of differences in the incidence of stress-related illnesses is therefore likely to be complex, and not confined to a single factor.

Encouraging progress is being made towards deriving a stress index, sensitive to differences in air traffic demands and to handling capacities[15]. If the research continues to be successful, it raises the issue of how a tool such as a stress index should be used. Some of the commonest findings about shift work, comparing sleep deprivation with various shift schedules, have not been verified when tested with air traffic controllers[16], and findings on controllers do not conform closely with what is known about diurnal rhythms. The physiological cost of the controller's work is therefore a matter of debate.

### 4.4 Boredom and Stress

While the problem of stress is undoubtedly serious and genuine in air traffic control, the recent emphasis on it has perhaps become excessive because it has led to the comparative neglect of other problems, particularly boredom. Many radar and plotting tasks for operators are intrinsically tedious so that it is difficult to reach and maintain highly efficient performance of them. Operators find it almost impossible to keep continuously alert, attentive and vigilant for a long period whilst scanning a display on which there



Dans la surveillance et le renforcement de ces mécanismes particuliers d'adaptation à une charge mentale exigeante, le problème essentiel, le vrai problème médical, est non pas la détection d'une pathologie spécifique à la fonction, ce qui paraît actuellement illusoire, chez certains individus du groupe, d'une symptomatologie clinique, is little to see. To increase the probability that a signal will be detected numerous strategems have been tried, from introducing additional false signals to providing automated aids or shortening periods of continuous working[7]. Boredom may not only reduce efficiency and morale but also impair safety. Incidents or infringements of separation standards in air traffic control are not always associated with heavy traffic, and the alleviation of stress would not necessarily decrease such incidents, since some occur in light traffic. If the system is manned to deal with peak traffic loadings, at other times the tasks may be boring and too undemanding for the intelligent people required to do the job.

Attempts to alleviate stress usually entail some reduction in workload, but the successful attainment of such a reduction may aggravate boredom and have further unforeseen consequences, related to a common dilemma in air traffic control. Behavioural measures of a controller handling traffic at a busy centre appear to show that he is overworked, often to the extent of performing several tasks concurrently. Physiological and biochemical indices of the effects of such a workload on him suggest that his performance is being achieved at considerable cost. Subjective assessments indicate that he is busy and may feel very tired by the end of his work period. The behavioural, physiological and subjective evidence agrees that he is working very hard, perhaps too hard, and so it is argued that his workload should be reduced. However, further questionning reveals that he likes to be busy and that the conditions which lead to stress and high workload also provide job interest, job satisfaction and opportunities to exercise skills. There is therefore some danger that any successful solution of the problems of stress and workload may introduce problems of boredom and dissatisfaction, which are themselves complex[17].

## 5. IMPLICATIONS OF AUTOMATION

### 5.1 Man and Machine

The progressive introduction of automation and computer assistance into air traffic control and air defence systems has led to several human factors problems, some specific to those systems and others associated with most large man-machine control systems. Much automation has been of benefit to the controller, but sometimes the needs of man at work have proved difficult to reconcile with demands for increased system capacity. Initially man and machine were treated competitively and lists were compiled of the functions suitable for each[18]. Only those functions which could conceivably be done by a machine tend to be included in such lists. Functions allocated to the man decrease with advances in technology, and they may be assigned to him not because he can do them well but because a machine cannot do them at all. If man and machine are presumed to be so similar that principles for allocating functions to one or other of them can be compiled, these can be expressed only in machine terms. The data handling capacity of the man may be discussed, but it is nonsense to discuss the pride of the machine. It does not follow because machine concepts are the only common language that they must be valid but rather that since their adoption is a matter of expediency their adequacy is bound to be limited.

A later development was to consider man and machine as complementary rather than competitive and to try and ensure that they matched each other rather than clashed in their allocated functions[19]. Lists of suitable functions for the man, compiled on this basis, can acknowledge human attributes whereas a more competitive approach cannot. Nevertheless many of the arguments against the competitive approach apply equally to the complementary one.

Comparing the man and the machine and assigning functions to each implies that there is one best way to perform each function. While this may generally be true for machines it is not always so for the man, particularly in command and problem solving roles where different strategies may be adopted and similar decisions may be implemented by several methods. If there is one best way to do a task, it should be followed; but if there is not, favoured individual methods which are safe and acceptable to others should be tolerated. Otherwise the man may interpret the imposition of a single method as unwarranted flouting of his professional skills and expertise.

From time to time strong pressures arise to introduce changes on the assumption that a technological advance must be an operational gain. It would be a considerable coincidence, however, if the operational need for a new device happened to occur at the same time as its first appearance on the market. Many recent advances in display technology give the impression of innovations looking for an application. A new display principle is likely to incorporate the normal human factors problems associated with displays and also one or two new problems peculiar to that principle. These might refer to renewal rate, clarity, persistence, relations to ambient lighting or legibility. Trials of new devices are intended to demonstrate their advantages but any disadvantages are never explored with comparable thoroughness. As a result, inadequacies may be revealed only when the equipment is in service. A current example is the interest in colour displays in air traffic control where its benefits are emphasised but its known deficiencies tend to be neglected[20].

### 5.2 Human Limitations and Needs

It is rare for an automated or computer-assisted function to replace the corresponding manual function in its entirety. At an early stage of automation the computer stores and collates data, and the controller or operator has a facility for the selective call-down of information onto a display. This may demonstrably reduce his workload, particularly if he does not have to enter information into the computer manually, but to retrieve information when it is needed the controller has the extra tasks of searching lists of items for the one he wants and of using keyboards to call it down. He also has to learn and remember what is available on call down.

Transponding of information can also save workload but at the cost of removing some qualitative sources of information from the system. As the volume of R/T communications between controller and pilot is reduced by direct transponding between air and ground, less information is available to each about the confidence and competence of the other. Each becomes less sensitive to the perceived needs of his listener. Information conveyed hitherto by tone of voice, intonation, pace of speech, pauses, phrasing and choice of language may be lost in automated data transmission.



DISCUSSION

As automation is introduced into decision making and problem solving, which depend more on the controller's skills and professional knowledge, his role is changed. The computer may provide solutions to problems which differ from those which the controller himself would have chosen. He tends to be uneasy about such solutions, particularly if he does not know enough about the factors which have influenced the computed solution to judge whether he should override it or not. The role of the computer may be to formulate solutions for the man to accept or reject. After a time, once he becomes convinced that the proposed solutions are always safe, the man may habitually accept them. If a solution is later called into question, he may not know why it was proposed and may not even remember what it was. Changes of this kind also have implications for responsibility and job status. They imply that selection and training methods should be re-examined: the abilities which once were appropriate for air traffic control or radar operating may be irrelevant in a more automated system where different skills are needed. If this has happened, it raises the issue of whether automation can be carried too far.

There is a tendency to presume that if the correct ergonomic procedures have been followed in task design and in the portrayal of all the necessary information for a job, then the man will be able to use the information presented and perform his tasks efficiently. Increasingly in air traffic control and air defence systems the distinction between the provision and the use of information is assuming importance[21]. It is not enough to provide all the necessary information without ensuring that it is in a form which the man can use and understand. Man's limitations in processing information and in perceptual judgement limit the quantity and format of information which he can assimilate, yet the extent of certain limitations only becomes clear when a task can be automated and comparisons are made between man and machine. Consistently efficient performance can seldom be achieved by a man at search, vigilance or monitoring tasks. He is also poor at recognising errors which are plausible. Stored information, available on call down, may never be used unless he can remember at the appropriate time that it is available. Well displayed relevant information which is not compatible with the man's normal thought processes may be ignored or misunderstood. It is often much simpler to formulate automated solutions to problems than to devise a reliable means of ensuring that the man can recall them.

Until recently, the discussion of many problems in system terms led to the comparative neglect of relevant factors which could not be expressed in such terms. There is now a greater awareness of the relevance of job attraction and job satisfaction[22], of challenge, of morale, of professional pride, of responsibilities and status, of the opportunities to acquire skills and to exercise them, and of the role of management[23], in the efficient performance of tasks in man machine systems. Although the importance of these factors is now acknowledged, many of the associated problems have not yet been solved or even seriously studied in air traffic control and radar operating systems. The potentially conflicting requirements of system efficiency and of the needs of man at work in a semi-automated system have still to be reconciled. The effects of automation on the man are the origin of many current and future psychological problems in these systems[24].

## 6. CONCLUSIONS

While the traditional visual and postural problems associated with radar and air traffic control tasks may continue to recur for some time, recent developments, particularly in display technology, provide a means for resolving many of them or reducing their incidence or seriousness. Problems such as matching ambient lighting with radar and other displays continue to appear but more satisfactory solutions should be possible in the future.

Stress as a problem, particularly in air traffic control, has now been acknowledged and is being actively studied. It is difficult however, to reduce stress and high workload levels without also reducing job interest, job satisfaction and the opportunities to exercise skills. A further problem is that of boredom, which becomes more serious as automated aids gradually replace manual functions.

In the allocation of functions to man and machine, only those which can be expressed in machine terms can be considered for such allocation. Certain qualitative aspects of tasks may therefore be ignored when allocations are made. Whether a given function should be done manually depends partly on the state of technological development: tasks may be assigned to the man not because he does them well but because the machine cannot do them at all. Automation affects performance and efficiency, and also the roles of memory and skill. As solutions to the traditional psychological problems become available new problems arise, some of which originated in the methods adopted to resolve the traditional problems within a progressively automated environment.

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## DISCUSSION

**Air Cdre J.N.C.Cooke, UK**

With the introduction of new and automated systems, do you find any evidence of the growth of a 'generation gap' between the older controllers and those who have little or no experience of the older methods.

**Author's reply**

There is already within air traffic control a gap between older controllers, trained initially in procedural methods, and younger controllers, familiar with radar from the onset. A gap may be developing between all existing controllers, used to mainly manual methods, and controllers recruited at present or in the future, who will be familiar with computer assistance from the outset. There is however, no evidence of a major generation gap among existing controllers in their attitude to automation. Most give it a cautious welcome, and hope to be convinced that it is of genuine assistance to them. The effects of automation, however, vary with age, because older controllers have greater difficulty in learning new methods, and particularly in forgetting old, familiar, but no longer relevant procedures.

# ETUDE STATISTIQUE SUR LA PATHOLOGIE DES CONTROLEURS-RADAR DE LA CIRCULATION AERIENNE

## SES RAPPORTS AVEC LE STRESS PROPRE A LA FONCTION

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RESUME

L'auteur présente les statistiques de la morbidité rencontrée dans deux catégories de contrôleurs-radar : un groupe de 693 contrôleurs militaires, utilisant du matériel non automatisé et un groupe de 149 contrôleurs civils utilisant un système très automatisé. Les statistiques y relatives portent respectivement sur 7 années et demi et 4 années.

Le taux annuel moyen d'élimination pour inaptitude physique ou mentale est faible : environ 0,5 %.

Les statistiques montrent une absence presque totale de pathologie visuelle et de pathologie auditive, chez les contrôleurs utilisant les équipements très automatisés.

La pathologie attribuable à la tension nerveuse est d'interprétation difficile. L'auteur s'est servi de deux critères : l'inaptitude physique et mentale en cours de carrière et les absences pour motifs de santé supérieures à 9 jours. Les affections qui auraient pu être causées ou aggravées par le stress inhérent à l'exercice de la profession sont peu nombreuses.

De la comparaison entre le taux de morbidité rencontrée dans le groupe de contrôleurs et les taux constatés dans un groupe d'assistants-contrôleurs, un groupe d'élèves et stagiaires et un groupe de personnel administratif et technique du même Centre de contrôle, il résulte qu'aucune pathologie spécifique propre aux contrôleurs-radar ne peut être clairement mise en évidence.

## INTRODUCTION

La détermination de la charge de travail du contrôleur-radar préposé au service de contrôle de la circulation aérienne fait actuellement l'objet d'études importantes. Elles portent sur l'emploi de critères psychologiques, physiologiques et opérationnels. Gerathewohl, Chiles et R.I. Thackray (1) - (2) ont fait récemment une mise au point de la question et ont cité, à cette occasion, les nombreux travaux publiés sur ce problème. Il est unanimement admis que cette charge, dans les Centres de contrôle desservant des grands aérodromes, peut être qualifiée d'élevée, soit d'une manière continue, soit à certaines périodes de la journée.

Le but de la présente étude est de rechercher si les réponses physiologiques et psychologiques qui accompagnent la performance des contrôleurs-radar peuvent aboutir, selon une fréquence significative, à des formes pathologiques particulières.

Les études statistiques relatives à la morbidité constatée chez les contrôleurs-radar sont peu nombreuses. En outre leur interprétation est difficile.

Pour notre étude, nous avons rassemblé des statistiques que nous avons récoltées dans deux groupes de contrôleurs-radar :

1° un groupe de 693 contrôleurs-radar de la Force aérienne belge : nous avons recherché les causes des inaptitudes physiques et mentales, survenues dans ce groupe pendant une période de 7 ans et demi (1er janvier 1963-30 juin 1970). Ce personnel n'a utilisé que des systèmes non automatisés;

2° un groupe de 149 contrôleurs-radar, en service dans un même centre de contrôle régional ou contrôle "en route", relevant d'Eurocontrol. Ce centre fonctionne selon un système hautement automatisé. Son personnel provient de sept nations d'Europe Occidentale. Nos observations portent sur 4 années consécutives (1972-1975). A défaut de cas d'inaptitude physique et mentale pendant cette période, nous avons recherché les causes médicales qui ont justifié les absences pour motifs de santé, à partir d'une certaine durée d'absence (absences supérieures à 9 jours).

Nous avons essayé de cerner le problème dans le cadre suivant. Nous considérons d'une manière distincte les trois aspects généralement étudiés dans la pathologie du contrôleur-radar :

1. la pathologie visuelle;
2. la pathologie auditive;
3. la pathologie causée par la tension nerveuse et la surcharge émotive. En ce qui concerne cette pathologie où se marqueraient les effets du stress, notre recherche s'est limitée, par souci de stricte objectivité, aux axes suivants, afin d'écarter l'intrusion de critères utilisant des données qui mériteraient le reproche d'avoir un caractère subjectif :

a) **Le stress inhérent aux activités du contrôleur-radar peut, par son intensité et sa répétition, avoir des effets tels que ces derniers aboutissent à créer l'inaptitude définitive à la fonction. D'où l'étude des causes médicales d'inaptitude définitive du personnel.**
b) **Le stress, sans déboucher sur cette extrémité, peut être suffisant pour causer des arrêts momentanés dans l'activité professionnelle. D'où l'étude des causes médicales responsables des absences pour motifs de santé.**

**Nous avons donc adopté deux critères objectifs pour classer nos données statistiques relatives aux effets du stress : l'inaptitude définitive à la fonction pour des raisons médicales et les absences d'une certaine durée pour cause médicale.**

Certes, le stress peut ne pas provoquer l'arrêt définitif ou momentané de l'activité professionnelle, mais être néanmoins suffisamment intense pour détériorer la performance et causer l'apparition d'une certaine symptomatologie qui est souvent à base de manifestations psycho-somatiques diverses. L'étude de la symptomatologie dont les rapports avec la charge du poste de travail ne peuvent être exclus a priori est intéressante. Mais, afin de ne prendre en considération que des critères objectifs, nous n'avons pas tenu compte de cette symptomatologie. C'est aussi la raison pour laquelle nous nous sommes abstenus d'utiliser la méthode des questionnaires à remplir par chaque membre du personnel faisant l'objet de l'étude.

Nous pensons néanmoins qu'avec les deux critères que nous avons choisis, nous avons retenu la majeure partie de la pathologie méritant considération pour les objectifs poursuivis.

## I. PATHOLOGIE VISUELLE

Nous avons longuement décrit dans des travaux antérieurs (3), (4), les facteurs visuels qui interviennent dans la présentation des données et dans leur lecture sur l'écran-radar et sur les tableaux d'affichage. Ils conditionnent l'existence ou l'absence de la pathologie visuelle. La fatigue visuelle des lecteurs de l'écran-radar, appelée aussi "fatigue opérationnelle du radariste", sur laquelle les travaux médicaux insistaient quand n'existait que le radar manuel, ne se rencontre presque plus avec le radar automatisé. Elle prend la forme d'une irritation oculaire du genre "conjonctivite", caractérisée par des picotements, des larmoiements, une congestion du bord libre des paupières, une hyperémie conjonctivale, des céphalées sus-orbitaires.

Dans les travaux publiés jusqu'aux environs de 1960, on note une assez grande discordance entre les auteurs sur la fréquence de cette fatigue, mais elle semble néanmoins avoir été importante. Mercier et Perdriel (5), dans un travail paru en 1961, signalent que 20 à 40 % des lecteurs examinés auraient présenté ces signes au cours de l'exercice de leur fonction pendant une période de 2 ans.

Nous avons recherché par l'étude des dossiers médicaux, l'existence de ces cas chez le personnel d'Eurocontrol. Rappelons que ce dernier utilise de l'équipement automatisé. Sur une période de 4 ans, nous avons relevé 10 cas chez les contrôleurs-radar, soit un pourcentage annuel moyen de 2,37. Un seul cas entraîna une absence supérieure à 9 jours.

A titre de comparaison, nous avons recherché l'existence de cas similaires chez les assistants-contrôleurs et chez les élèves-contrôleurs. Nous avons relevé 4 cas chez les assistants-contrôleurs, soit un pourcentage annuel moyen de 1,88. Il n'y eut pas de cas chez les élèves-contrôleurs.

Ces faibles pourcentages montrent que cette pathologie est en très nette régression. Elle est appelée à disparaître ou à ne se manifester que très occasionnellement dans des circonstances spéciales (intensité lumineuse excessive produite lors du dérangement d'un scope, mauvais réglage du rythme des images lumineuses, etc...).

Les critères visuels de sélection, les conditions modernes de visualisation des données sur l'écran dans une ambiance lumineuse comprise entre 160 et 200 lux, et les progrès techniques qui ont abouti à supprimer le scintillement des images lumineuses (flicker) permettent maintenant de réduire considérablement ou de supprimer les sources de la fatigue visuelle et de la pathologie qui lui est liée dans le travail à l'écran.

## II. PATHOLOGIE AUDITIVE

Elle ne présente aucun caractère particulier chez les contrôleurs de la circulation aérienne.

Quand elle se produit, elle se manifeste comme chez l'aviateur par une réduction insidieuse de l'acuité auditive sur les fréquences de 3000 et 4000 hertz; ensuite le trou auditif gagne les fréquences moins élevées. Cette fatigue auditive est relativement peu fréquente dans la pathologie propre au contrôleur-radar.

1. Dans le groupe des contrôleurs d'Eurocontrol, nous avons rencontré en un an trois cas de contrôleurs ayant un déficit supérieur à 20 décibels ASA sur la fréquence de 3000 hertz à une oreille, mais répondant encore aux conditions d'aptitude. Nous n'avons rencontré aucun cas présentant un tel déficit chez les élèves, les stagiaires et les assistants-contrôleurs.
2. Chez 382 contrôleurs de la Force aérienne belge (3), surveillés au cours d'une période de 7 ans et demi, trois sujets ont été éliminés en raison des déficiences auditives, soit un taux annuel d'élimination de 0,105%

3. Dans la statistique américaine citée par Zetzmann (6), on trouve 30 cas d'inaptitude pour déficiences auditives dans une série de 12.500 contrôleurs surveillés pendant 25 mois, soit un taux annuel d'élimination de 0, 115 %.

Il semble donc raisonnable de dire que le taux annuel d'élimination pour raisons auditives est faible et se situe aux environs de 0,1 %.

## III. PATHOLOGIE DUE A LA TENSION NERVEUSE

### 1. Généralités

#### (1) Causes

La fonction essentielle du contrôleur, dans l'accomplissement de son travail, est la prise de décisions sur le déplacement des avions dans le secteur qu'il est chargé de contrôler : choix des niveaux de vol, de la route à suivre, de la modification de la trajectoire lors de la détection des situations de conflits avec l'itinéraire suivi par d'autres avions et lors de la détection des retards dans l'écoulement de la circulation aérienne en cas d'encombrement d'un secteur, etc...

Dans les systèmes non automatisés, le contrôleur doit, en outre, préparer, classer et ordonner les informations servant de base à sa décision. Il ne dispose que d'informations relativement brutes qu'il doit d'abord raffiner.

Dans les systèmes très automatisés - c'est le cas pour le centre d'Eurocontrol que nous avons étudié - les machines peuvent aider le contrôleur dans son pouvoir de décision. Dans ce cas, le contrôleur peut n'avoir qu'à analyser les données élaborées en équipe et présentées d'une manière rationnelle par les machines. Mais, en définitive, si son travail est grandement facilité, la responsabilité de l'entérinement de la décision proposée lui incombe encore, après qu'il ait clairement identifié et vérifié les paramètres sur lesquels repose sa décision.

Même avec l'aide considérable qu'apportent les nouveaux systèmes hautement spécialisés, les activités d'un contrôleur de la circulation aérienne demeurent stressantes par nature.

Il n'est pas douteux que les responsabilités à assumer, l'intensité du travail à certaines heures de circulation dense ou complexe, la concentration soutenue de l'attention, la conscience des conséquences catastrophiques d'une erreur créent une situation de tension constante. Celle-ci peut aboutir à la surcharge émotive chez des sujets dont le contrôle psychique est labile ou s'est affaibli à mesure que la tension croît. Il en résulte alors un surmenage nerveux dont la cause est attribuable à la répétition des surcharges émotives. Il va de soi que l'intensité de la charge de travail peut varier d'un centre à l'autre et, dans un même centre, d'une heure à l'autre.

#### (2) Facteurs favorisants

Un rôle favorisant dans l'apparition de ce surmenage nerveux est dévolu à un certain nombre de facteurs. On les rencontre dans de nombreux autres syndrômes de fatigue.

Les plus importants sont des facteurs totalement extrinsèques au milieu de travail : difficultés familiales, conjugales, ennuis financiers, professionnels, activité accessoire lucrative mais fatigante pendant les heures de loisir, etc...

D'autres facteurs sont liés au lieu et aux conditions de travail. Ils tendent à perdre beaucoup de leur importance en raison des améliorations nombreuses qui ont été apportées récemment à beaucoup de centres de contrôle. Ces facteurs sont, par exemple, le bruit du milieu environnant, la température excessive régnant parfois dans des salles de travail non climatisées, le séjour en milieu confiné ou souterrain, etc... Il est très difficile d'évaluer la part de tous ces facteurs, qui s'ajoutent au stress professionnel, dans le stress global qui affecte l'individu.

#### (3) Facteurs de défense de l'individu contre le stress

Le stress n'a de sens que lorsqu'il est rapporté à l'individu qui le subit. C'est pourquoi, on ne doit pas seulement connaître la nature et l'intensité du stress. Il faut encore tenir compte de la capacité de résistance du sujet qui subit le stress, des moyens de défense qu'il trouve dans sa personnalité, son groupe social et son milieu professionnel (cadence des périodes de travail et de repos, congés réguliers, répartition appropriée du travail de nuit, cohésion des équipes, etc...).

#### (4) Manifestations psycho-somatiques du stress

On s'est demandé si la répétition des surcharges émotives chez le personnel des services de contrôle de la circulation aérienne et plus particulièrement celui du contrôle radar, ne provoque pas une usure physiologique plus rapide que dans d'autres groupes de personnel ayant des occupations moins stressantes. Pour tenter d'apporter une réponse, nous avons appliqué les deux critères que nous avons déjà mentionnés plus haut, pour évaluer les effets du stress sur la santé du contrôleur.

2. Etudes statistiques sur l'inaptitude physique ou mentale définitive à la fonction

Les statistiques qui paraissent les plus objectives et les moins sujettes à controverses dans leur interprétation sont celles qui portent sur les causes médicales d'inaptitude physique et mentale chez les contrôleurs de la circulation aérienne en cours de carrière, après une durée minima de 2 ans de service. Rappelons que Zetzmann (6), précédemment mentionné, cite les causes médicales d'inaptitude chez 147 contrôleurs américains des services civils de contrôle de la circulation aérienne sur un total de 12.500 contrôleurs surveillés pendant 25 mois. Le taux annuel moyen d'éliminations pour inaptitude physique ou mentale est donc de 0,588 %.

Selon Zetzmann, trois groupes d'affections, attribuables au stress dans une certaine mesure, représentent 45,6 % de la pathologie causale des inaptitudes (67 cas). Ce sont :
- des affections cardio-vasculaires 24,5 %;
- des affections neuro-psychiques 12,5 %;
- des affections gastro-intestinales et métaboliques 8,6 %.

Le taux d'élimination où l'action causale du stress est probable est donc de 0,257 par 100 hommes par an.

a) Dans le groupe des 693 contrôleurs-radar de la Force aérienne belge, 15 sujets furent éliminés pour inaptitude physique ou mentale au cours de la période de 7 ans et demi étudiée.

Ce groupe se décompose comme suit :

367 sujets sont demeurés aptes au cours de la période étudiée;
15 sujets sont devenus inaptes pour des raisons médicales, après plus de 2 ans de service;
311 sujets quittèrent le service au cours de la période étudiée pour des raisons n'ayant aucun rapport avec leur aptitude physique ou mentale (démission, mise à la retraite, mutation d'emploi, etc...). Ils ne peuvent donc être retenus pour les calculs statistiques de morbidité.

Le tableau 1 fournit les causes médicales de l'inaptitude physique ou mentale et l'âge des sujets.

Tableau 1 - Causes d'inaptitude physique ou mentale à la fonction de contrôleur dans la Force aérienne belge de 1963 à 1970.

| Causes médicales d'inaptitude physique ou mentale | Nombre de cas | Age | Remarques |
|---|---|---|---|
| 1. Affections neuro-psychiques | | | |
| Névroses d'anxiété | 8 | 48 ans<br>42 ans<br>40 ans<br>40 ans<br>39 ans<br>37 ans (1)<br>36 ans<br>34 ans | (1) Sujet présentant en outre un ulcère peptique |
| Crises convulsives d'origine indéterminée | 1 | 40 ans | |
| 2. Système cardio-vasculaire | | | |
| Hypertension | 1 | 47 ans | |
| Sténose aortique | 1 | 37 ans | |
| 3. Vision | | | |
| Déficience visuelle | 1 | 31 ans | |
| 4. Audition | | | |
| Déficience auditive | 3 | 31 ans<br>35 ans<br>43 ans (2) | (2) fut antérieurement membre du Personnel navigant (navigateur) |

Pour les 382 contrôleurs entrant en ligne de compte, le coefficient annuel moyen d'inaptitude physique ou mentale est de 0,54 %. Il est donc similaire à celui fourni par l'étude de Zetzmann. Quant au taux annuel moyen d'élimination pour des affections où l'action causale du stress est probable, il est de 0,314 % en utilisant la même classification que celle de Zetzmann. Ce taux est relativement proche de celui fourni par la statistique américaine de cet auteur. Toutefois, la répartition des affections causales attribuables au stress par rapport à toutes les causes d'inaptitude est différente :
- affections neuro-psychiques 53,33 %;
- affections cardio-vasculaires 6,66 %.

On doit admettre que les taux annuels d'élimination, que l'on trouve dans les deux groupes cités sont très faibles. Il est probable qu'ils ne correspondent pas d'une manière stricte à la réalité et qu'ils devraient être un peu plus élevés. En effet, il est impossible de déterminer dans quelle mesure du personnel démissionnaire et du personnel ayant obtenu, à sa demande, un changement de fonction, ont présenté une baisse de motivation à la suite d'un état d'anxiété. Cet état, s'il devient de plus en plus insupportable en raison des responsabilités inhérentes aux prises de décision dans des situations difficiles, peut avoir incité le sujet à quitter le service. La vraie nature du cas échappe ainsi aux autorités médicales et aux statistiques médicales. Même en tenant compte de cette correction, on peut estimer que le taux annuel moyen d'éliminations pour inaptitude physique ou mentale se situe entre 0,5 et 0,8 %.

b) Dans le groupe des contrôleurs-radar d'Eurocontrol que nous avons suivis pendant 4 ans, il n'y eut aucune élimination pour inaptitude physique ou mentale.

Ceci n'a rien d'étonnant en raison du nombre restreint de sujets faisant l'objet de l'étude, de leur sélection préalable à l'admission, de la durée relativement courte de l'observation (4 ans), de l'âge des sujets dont plus de 80 % n'ont pas 40 ans (voir tableau 2).

Tableau 2 - Répartition des contrôleurs-radar selon leur âge

| Catégories d'âge | Pourcentage des sujets par catégorie d'âge et par année étudiée | | | |
|---|---|---|---|---|
| | 1ère année 73 sujets | 2ème année 91 sujets | 3ème année 108 sujets | 4ème année 149 sujets |
| 19 - 24 ans | 15,06 | 8,79 | 3,70 | 1,34 |
| 25 - 29 ans | 21,91 | 27,47 | 19,44 | 30,20 |
| 30 - 34 ans | 20,54 | 16,48 | 33,33 | 30,87 |
| 35 - 39 ans | 23,28 | 27,47 | 27,77 | 24,16 |
| 40 - 44 ans | 10,96 | 10,99 | 7,41 | 5,37 |
| 45 - 49 ans | 8,22 | 8,79 | 8,33 | 6,71 |
| 50 - 55 ans | - | - | - | 1,34 |

3. Etudes statistiques sur les absences pour motifs de santé

Dans la recherche des causes des absences pour motifs de santé, nous avons tenu compte que selon la réglementation en vigueur à Eurocontrol, des absences d'un, deux ou trois jours ne doivent pas être nécessairement justifiées par un certificat médical jusqu'à un total de 12 jours d'absence par période de 12 mois. Il est donc pratiquement impossible de connaître les raisons médicales véritables et précises de tous ces brefs congés. On peut supposer qu'il s'agit le plus souvent d'indispositions de courte durée, d'épisodes de fatigue, de soins dentaires, d'affections de gravité mineure. C'est pourquoi, d'une manière arbitraire, nous n'avons recherché les motifs médicaux d'absence qu'à partir d'un total annuel de 10 jours d'absence au moins.

Puisque le but de l'étude est de rechercher l'existence éventuelle d'une pathologie propre aux contrôleurs-radar, liée à la charge de travail et au stress de la profession, il nous a paru nécessaire d'introduire un élément de comparaison avec d'autres catégories de sujets soumis à des conditions de milieu similaires mais ne participant pas à ce stress spécifique. C'est pourquoi l'étude a également porté au cours de ces quatre années :
a. sur des élèves contrôleurs en formation ou en stage de perfectionnement;
b. sur des assistants-contrôleurs.

Ces derniers sont des aides intimement associés au travail des contrôleurs. Leurs activités se passent dans le même milieu, mais ils ne supportent pas le poids du stress lié à la responsabilité des prises de décision, ni la tension nerveuse que provoquent l'encombrement des routes aériennes et certaines situations difficiles dans le secteur aérien sous contrôle. En outre, pour pouvoir compléter les comparaisons, nous avons également rassemblé des données numériques relatives aux absences pour raisons de santé du personnel administratif et technique du même Centre, pendant une période d'un an.

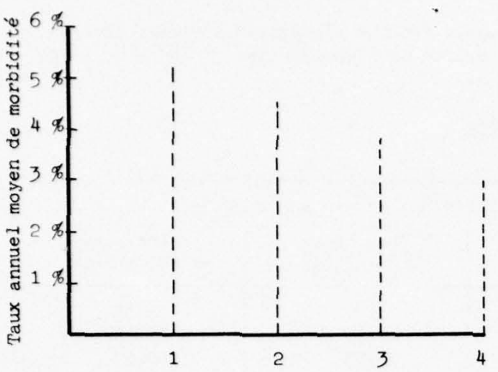
Les trois catégories de personnel affecté au service opérationnel du contrôle aérien se répartissent comme suit durant les 4 années sur lesquelles porte l'étude (voir tableau 3).

Tableau 3 - Répartition du personnel opérationnel du contrôle aérien

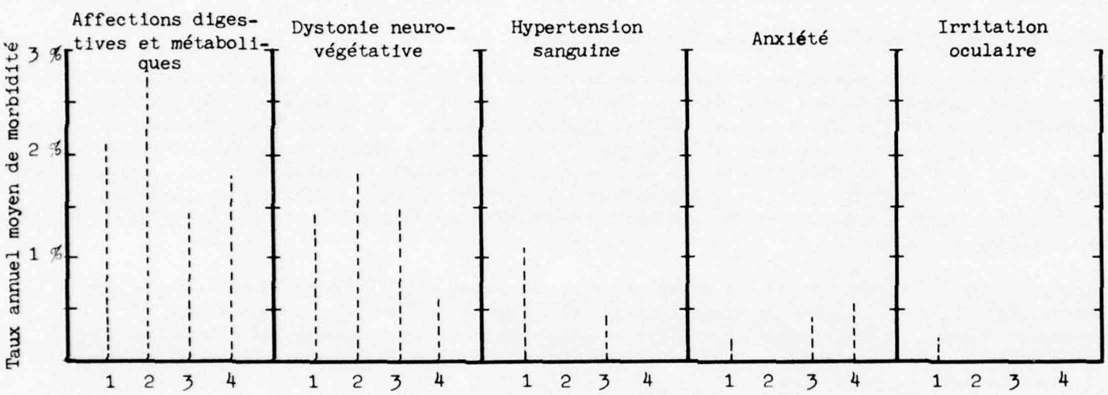
| Années | Nombre de contrôleurs-radar | Nombre d'élèves-contrôleurs et de stagiaires | Nombre d'assitants-contrôleurs |
|---|---|---|---|
| 1ère année | 73 | 29 | 25 |
| 2ème année | 91 | 50 | 69 |
| 3ème année | 108 | 82 | 61 |
| 4ème année | 149 | 46 | 62 |

En raison de l'influence possible de l'âge sur la pathologie étudiée, le relevé statistique de celle-ci est toujours précédé d'un tableau indiquant la répartition des sujets d'après leur âge. Pour l'âge des contrôleurs, on se reportera au tableau 2, déjà présenté ci-avant.

Graphique 1 - Taux annuel moyen de morbidité attribuable au stress et provoquant des absences supérieures à 9 jours par an




Graphique 2 - Taux annuel moyen de morbidité attribuable à des classes de maladies pouvant être dues au stress




a. Absences chez les contrôleurs-radar

Le tableau 4 fournit la répartition des contrôleurs-radar selon la durée de leurs absences pour raisons de santé.

Tableau 4 - Répartition des contrôleurs-radar selon la durée des absences pour raisons de santé

| Nombre de jours d'absence pour raisons de santé | 1ère année | | 2ème année | | 3ème année | | 4ème année | |
|---|---|---|---|---|---|---|---|---|
| | Nombre de sujets | % | Nombre de sujets | % | Nombre de sujets | % | Nombre de sujets | % |
| 0 jour | 22 | 30,1 | 14 | 15,38 | 16 | 14,8 | 23 | 15,43 |
| 1 à 9 jours | 40 | 54,8 | 30 | 51,65 | 50 | 46,3 | 74 | 49,66 |
| 10 à 20 jours | 5 | 6,85 | 19 | 20,88 | 28 | 25,9 | 34 | 22,81 |
| plus de 20 jours | 6 | 8,25 | 11 | 12,09 | 14 | 13,0 | 18 | 12,08 |

Au total, il y eut en 4 ans 135 cas dont la durée des absences pour raisons de santé totalisa plus de 9 jours par an.

Nous appliquons les mêmes critères que ceux utilisés par Zetzmann pour le classement des maladies où le stress a probablement joué le rôle d'agent causal ou aggravant.

Sur les 135 cas d'absence, nous avons relevé que dans 22 cas, il est probable, mais non prouvé, que l'affection pourrait avoir été causée ou aggravée par le stress inhérent à l'exercice de la profession ou à la charge de travail qu'elle comporte.

Ce sont :

- hypertension sanguine de caractère labile (hypertension supérieure à 150-90 mm de mercure) — 5 cas
- affections gastro-intestinales
  - (1) gastrites et gastro-entérites chroniques — 7 cas
  - (2) ulcères gastriques ou duodénaux — 2 cas

- dystonie neuro-végétative 7 cas
- épisode anxieux 1 cas

Ces 22 cas représentent 16,3 % de l'ensemble du groupe des contrôleurs ayant été absents pendant plus de 9 jours par an pour des raisons de santé.

b. Absences chez les élèves-contrôleurs et stagiaires

La répartition du personnel d'après l'âge est fournie par le tableau 5.

Tableau 5 - Répartition des élèves-contrôleurs et stagiaires d'après l'âge

| Catégories d'âge | Pourcentages de sujets par catégorie d'âge et par année | | | |
|---|---|---|---|---|
| | 1ère année 29 sujets | 2ème année 50 sujets | 3ème année 82 sujets | 4ème année 46 sujets |
| 19 - 24 ans | 34,48 | 20 | 21,95 | 23,91 |
| 25 - 29 ans | 51,72 | 46 | 48,78 | 41,33 |
| 30 - 34 ans | 13,68 | 28 | 21,95 | 32,61 |
| 35 - 39 ans | - | 6 | 6,09 | 2,17 |
| 40 - 44 ans | - | - | 1,22 | - |
| 45 - 49 ans | - | - | - | - |

Pour la période considérée, la quasi-totalité des sujets n'atteint pas l'âge de 40 ans

La répartition des élèves-contrôleurs et des stagiaires s'établit comme suit, d'après la durée des absences pour raisons de santé (voir tableau 6).

Tableau 6 - Répartition des élèves-contrôleurs et stagiaires selon la durée des absences pour raisons de santé

| Nombre de jours d'absence pour raisons de santé | 1ère année | | 2ème année | | 3ème année | | 4ème année | |
|---|---|---|---|---|---|---|---|---|
| | Nombre de sujets | % | Nombre de sujets | % | Nombre de sujets | % | Nombre de sujets | % |
| 0 jour | 11 | 37,93 | 16 | 32 | 24 | 29,26 | 8 | 17,39 |
| 1 à 9 jours | 14 | 48,28 | 23 | 47 | 45 | 54,88 | 25 | 54,34 |
| 10 à 20 jours | 2 | 6,89 | 7 | 14 | 8 | 9,76 | 9 | 19,56 |
| plus de 20 jours | 2 | 6,89 | 4 | 8 | 5 | 6,10 | 4 | 8,69 |

Au total, il y eut 41 cas dont la durée des absences pour raisons de santé totalisa plus de 9 jours par an.

Ce n'est que dans 10 cas qu'il est probable, mais non prouvé, que l'affection puisse avoir été causée ou aggravée par le stress inhérent à l'apprentissage de la fonction ou à la charge de travail qu'elle comporte. Ces 10 cas sont :

- Hypertension sanguine de caractère labile (supérieure à 150-90 mm de mercure) 1
- Système digestif
  (1) gastrites ou gastro-entérites chroniques 3
  (2) ulcus gastrique ou duodénal 0
- Diabète sucré non insulino-dépendant 1
- Dystonie neuro-végétative 4
- Episode anxieux 1

Ces 10 cas représentent 24,39 % de l'ensemble du groupe des élèves-contrôleurs et stagiaires ayant été absents plus de 9 jours par an pour des raisons de santé. Ce pourcentage est supérieur à celui relevé dans le groupe des contrôleurs (16,3 %).

c. Absences chez les assistants-contrôleurs

La répartition des assistants-contrôleurs d'après l'âge est fournie par le tableau 7.

Tableau 7 - Répartition des assistants-contrôleurs d'après l'âge

| Catégories d'âge | Pourcentages de sujets par catégorie d'âge et par année | | | |
|---|---|---|---|---|
| | 1ère année 25 sujets | 2ème année 69 sujets | 3ème année 61 sujets | 4ème année 62 sujets |
| 19 - 24 ans | 24 | 37,68 | 21,31 | 12,90 |
| 25 - 29 ans | 56 | 43,48 | 42,62 | 51,61 |
| 30 - 34 ans | 20 | 15,94 | 31,14 | 29,03 |
| 35 - 39 ans | - | 2,89 | 4,92 | 4,85 |
| 40 - 44 ans | - | - | - | 1,61 |
| 45 - 49 ans | - | - | - | - |

Pour la période considérée, dans leur quasi-totalité, ces sujets sont âgés de moins de 40 ans.

La répartition des assistants-contrôleurs selon la durée des absences pour raisons de santé est fournie par le tableau 8.

Tableau 8 - Répartition des assistants-contrôleurs selon la durée des absences pour raisons de santé

| Nombre de jours d'absence pour raisons de santé | 1ère année | | 2ème année | | 3ème année | | 4ème année | |
|---|---|---|---|---|---|---|---|---|
| | Nombre de sujets | % | Nombre de sujets | % | Nombre de sujets | % | Nombre de sujets | % |
| 0 jour | 6 | 24 | 14 | 20,28 | 10 | 16,39 | 4 | 6,45 |
| 1 à 9 jours | 12 | 48 | 39 | 56,52 | 31 | 50,82 | 31 | 50 |
| 10 à 20 jours | 3 | 12 | 11 | 15,94 | 13 | 21,31 | 18 | 29,03 |
| Plus de 20 jours | 4 | 16 | 5 | 7,26 | 7 | 11,48 | 9 | 14,52 |

Au total, il y eut 70 cas dont la durée des absences pour raisons de santé totalisa plus de 9 jours par an.

Ce n'est que dans 9 cas qu'il est probable, mais non prouvé, que l'affection puisse avoir été causée ou aggravée par le stress inhérent à l'exercice de la fonction ou à la charge de travail qu'elle comporte. Ce sont :

- Système digestif
  - (1) gastrites et gastro-entérites chroniques 5
  - (2) ulcus gastrique ou duodénal 0
- Dystonie neuro-végétative 4

Ces 9 cas représentent 12,85 % de l'ensemble du groupe des assistants-contrôleurs ayant été absents plus de 9 jours par an pour des raisons de santé. Ce pourcentage est donc inférieur à celui relevé dans le groupe des contrôleurs.

d. Absences chez le personnel administratif et technique ne participant pas aux activités opérationnelles du contrôle aérien

Afin de compléter les possibilités de comparaison avec le groupe des contrôleurs, nous avons groupé dans le tableau 9 les absences pour raisons de santé se rapportant au personnel administratif et technique du Centre de contrôle aérien où fonctionne le groupe de contrôleurs faisant l'objet de cette étude. Ce personnel administratif et technique comprend 158 personnes. Les statistiques ne se rapportent qu'à une seule année.

Tableau 9 - Répartition du personnel administratif et technicien selon la durée des absences pour raisons de santé

| Nombre de jours d'absence pour raisons de santé | Nombre de sujets | Pourcentage |
|---|---|---|
| 0 jour d'absence | 55 | 34,81 |
| de 1 à 9 jours | 63 | 39,87 |
| de 10 à 20 jours | 26 | 16,45 |
| plus de 20 jours | 14 | 8,85 |

Au total, il y eut donc 40 personnes (25,32 %) dont la durée des absences pour raisons de santé totalisa plus de 9 jours par an.

Ce n'est que dans 5 cas qu'il est probable, mais non prouvé, que l'affection puisse avoir été causée ou aggravée par le stress lié à la charge de travail inhérente à la profession.

Ce sont :

- Affections gastriques 3 cas
- Dystonies neuro-végétatives 1 cas
- Affection psychiatrique 1 cas

Ces 5 cas représentent 12,5 % de l'ensemble du groupe de ce personnel ayant été absent plus de 9 jours au cours de l'année pour des raisons de santé.

Ce pourcentage est analogue à celui du groupe des assistants-contrôleurs et inférieur à celui du groupe des contrôleurs (16, 3 %).

e. Comparaison de certaines données statistiques relevées dans les divers groupes étudiés

On a expliqué plus haut les raisons pour lesquelles les absences inférieures à 10 jours sont dépourvues de valeur d'interprétation dans l'optique qui nous intéresse. Pour les quatre groupes de sujets, nous avons rassemblé dans cinq classes, correspondant aux grands systèmes, les maladies qui sont causes des absences supérieures à 9 jours par an et dont les rapports avec le stress professionnel sont possibles ou probables. Dans le but d'établir des comparaisons, nous avons calculé pour chacun des 4 groupes de personnes, le taux de morbidité annuelle moyenne. On obtient les résultats ci-après (tableau 10).

Tableau 10 - Morbidité annuelle moyenne en % dans les classes d'affections pouvant être dues au stress et intervenant comme causes d'absences pour motifs de santé, supérieures à 9 jours par an

| Classes de maladies | Fréquence annuelle moyenne des cas d'absence pour raisons de santé, par groupe de 100 sujets | | | |
|---|---|---|---|---|
| | Contrôleurs | Elèves et stagiaires | Assistants-contrôleurs | Personnel administratif et technique |
| Système digestif et métabolisme | 2,137 | 1,449 | 2,765 | 1,900 |
| Dystonie neuro-végétative | 1,425 | 1,449 | 1,843 | 0,632 |
| Hypertension sanguine (labile) | 1,187 | 0,483 | - | - |
| Anxiété | 0,237 | 0,483 | - | 0,632 |
| Irritation oculaire | 0,237 | - | - | - |
| Total | 5,223 | 3,864 | 4,608 | 3,164 |

C'est par le facteur "hypertension sanguine, de caractère labile", que les contrôleurs se différencient le plus nettement des autres groupes. On notera que ce même facteur est également présent, mais à un taux nettement plus faible, chez les élèves et stagiaires. Le facteur "irritation oculaire" n'est présent que chez les contrôleurs. Par contre, le facteur "système digestif", qui a la fréquence la plus élevée dans chacun des 4 groupes, ne montre aucune différenciation nette, d'un groupe à l'autre.

La dystonie neuro-végétative prédomine nettement dans les 3 groupes impliqués dans les aspects opérationnels du contrôle aérien, puisque ce facteur est ramené à une importance deux fois moindre chez le personnel administratif et technique.

L'anxiété est peu importante dans le groupe des contrôleurs. On peut expliquer le fait par l'élimination antérieure des personnalités anxieuses, dans la phase initiale d'instruction ou dans la première partie de la carrière.

La comparaison entre les taux de morbidité annuelle moyenne se rapportant à chacun des 4 groupes de personnel est intéressante (voir graphiques 1 et 2).

Ce taux est de 5,223 % pour les contrôleurs (de 4,966 % si l'on ne tient pas compte du facteur d'irritation oculaire).

Ce taux est de 3,864 % pour le groupe des élèves et stagiaires.

Il est de 4,608 % pour le groupe des assistants-contrôleurs.

Il est de 3,164 % pour le personnel administratif et technique.

On constate donc que le taux de morbidité annuelle moyenne limitée aux classes d'affections pouvant être dues au stress est d'autant plus élevé que le groupe de personnel est astreint à une responsabilité plus élevée dans les décisions immédiates et à une tension plus intense et plus continue dans sa charge de travail. En effet, le classement résultant de ce taux présente un caractère de concordance avec la grandeur du stress professionnel supposé, puisque par ordre décroissant on trouve :

1) le groupe des contrôleurs (5,223 %);
2) le groupe des assistants-contrôleurs (4,608 %);

3) le groupe des élèves et stagiaires (3,864 %);
4) le personnel administratif et technique ne participant pas au contrôle aérien (3,164 %).

Toutefois, les différences entre les groupes sont faibles et n'isolent pas d'une manière tranchée le groupe des contrôleurs. Le critère des absences pour motifs de santé n'apporte donc pas une preuve convaincante de l'existence d'une pathologie professionnelle propre aux contrôleurs-radar.

Ces mêmes études statistiques, si elles portaient sur des groupes beaucoup plus nombreux, procureraient peut-être un peu plus de clarté. En attendant, rien ne permet d'affirmer l'existence de cette pathologie spécifique des contrôleurs, conditionnée par le stress propre à l'exercice de leurs fonctions.

## IV. CONCLUSIONS

1. La surcharge imposée d'une manière répétée au système nerveux est un fait incontestable qui mérite la plus grande attention en vue d'en réduire les effets sur les organismes mal adaptés ou particulièrement sensibilisés aux situations stressantes de la profession.

   Les effets de l'automatisation des équipements sur la performance et ceux de différentes cadences du complexe travail-repos sont susceptibles de réduire l'importance des effets du stress des contrôleurs. Ces matières sont l'objet de nombreuses études ergonomiques. Mais, il faut bien reconnaître que l'on ne possède pas encore une évaluation opérationnelle suffisamment longue des nouvelles caractéristiques des systèmes, bien qu'il soit indéniable qu'elles réduisent la fatigue visuelle et qu'il semble qu'elles réduisent la fatigue psychique du contrôleur-radar.

2. Les deux groupes que nous avons étudiés doivent être considérés comme des entités ayant leurs particularités propres. Outre les caractéristiques du travail et du milieu où celui-ci se déroule, l'âge moyen d'un groupe est un facteur important qui influe sur la pathologie qui s'y manifeste. Il n'est donc pas permis de généraliser à l'ensemble des contrôleurs-radar d'un pays ou d'un groupe de pays, les conclusions que l'on a pu tirer de l'analyse des statistiques relatives à ces deux groupes. Les statistiques que nous produisons établissent que, pendant les périodes étudiées, les affections attribuables avec vraisemblance au stress nerveux n'ont pas eu une fréquence anormale, n'ont pas provoqué des éliminations excessives et que, par conséquent, les capacités de récupération et d'adaptation sont demeurées, d'une manière générale, amplement satisfaisantes.

3. Un autre aspect qui mérite attention est celui de la signification qu'il faut accorder à l'évaluation statistique de la morbidité chez les contrôleurs-radar.

   (1) Cette pathologie <u>n'a pas de caractère spécifique</u>. La comparaison, au point de vue de leur pathologie, entre le groupe des contrôleurs soumis à de lourdes responsabilités et à de vives tensions d'une part, celui des élèves-contrôleurs, celui des assistants-contrôleurs, et le groupe administratif et technique, tous trois soumis à des stress professionnels infiniment moins intenses d'autre part, ne montre pas des différences suffisamment nettes qui permettraient d'établir des caractères propres à la pathologie des contrôleurs.

   (2) De plus, la pathologie rencontrée <u>ne mesure pas la charge de travail</u>, en raison des variations individuelles considérables dans les mécanismes défensifs mis en jeu par chaque sujet pour répondre au stress. Elle ne permet que de constater certains signes d'alarme, quand l'équilibre entre la pression du stress et la puissance des défenses offertes par l'individu et par le groupe est vacillant ou déjà compromis.

   Ces conclusions ne diffèrent pas de celles déjà trouvées dans d'autres professions soumises à des stress nerveux extrêmement intenses. C'est notamment le cas pour les aviateurs militaires. Nous avons pu démontrer, en 1955 (7), sur la base d'importantes statistiques américaines, britanniques, françaises et belges, que l'ulcère gastro-duodénal n'atteint pas le groupe des aviateurs militaires, même en temps de guerre, d'une manière plus élective que des groupes appartenant à une autre profession, moins sujette aux chocs émotifs et aux tensions psychiques. Morhouse (8) a d'ailleurs confirmé que, pour les cas admis dans les hôpitaux de l'USAF, il ne semble pas y avoir un pourcentage d'admissions plus élevé chez le personnel navigant de l'USAF que chez le personnel non navigant en ce qui regarde l'ulcus gastro-duodénal.

   (3) En ce qui se rapporte au contrôleur-radar, le médecin se trouve en face d'une situation qui, par beaucoup d'aspects, est similaire à celle de l'aviateur. La ligne de pensée ne peut donc différer, sur le plan médical, de ce qui a été établi par les nombreuses études menées sur le stress de l'aviateur et sur sa pathologie spécifique. Ces études n'ont jamais pu établir une relation nette, valable pour l'ensemble d'un groupe important d'aviateurs, entre la morbidité survenant dans ce groupe et le stress émotif intense que suscitent certaines conditions de vol. Il en est de même pour le groupe des contrôleurs-radar qui a fait l'objet de cette étude. Si le médecin est souvent désarmé pour réduire substantiellement la charge de travail et la puissance agressive du stress qui lui est liée, il peut, du moins, contribuer à renforcer, pour l'individu et pour le groupe où il est inséré, la valeur des facteurs qui fortifient la capacité de résistance et d'adaptation de chaque individu devant les pressions du milieu externe et du milieu interne afin de sauvegarder le niveau de performance et la santé du sujet.

Dans la surveillance et le renforcement de ces mécanismes particuliers d'adaptation à une charge mentale exigeante, le problème essentiel, le vrai problème médical, est non pas la détection d'une pathologie spécifique à la fonction, ce qui paraît actuellement illusoire, mais le repérage précoce, chez certains individus du groupe, d'une symptomatologie clinique, habituellement liée à un état de tension mentale excessive.

Ce repérage joue un double rôle important : celui de signal d'alarme et celui d'indicateur sur l'efficacité des mesures prises par l'individu et par l'autorité pour contrecarrer les effets du stress et maintenir l'équilibre physiologique et psychique.

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by direct transponding between air and ground, less ... Information
competence of the other. Each becomes less sensitive to the perceived needs of his listener.
conveyed hitherto by tone of voice, intonation, pace of speech, pauses, phrasing and choice of language may be lost in automated data transmission.



## DISCUSSION

**Dr Fuchs, Germany**

What kind of criteria did you use for the determination of the so called "stress attributed inaptitude"?

**Author's reply**

I used the list of diseases given by Zetzmann in his paper "Workload and performance limiting factors of the Air Traffic Control Radar Operations", published in the AGARD Conference Proceedings No. 74. (Rest and activity cycle for the maintenance of efficiency of personnel concerned with the military flight operations, by Benson). As reported in this paper, this list was used for American research works sponsored by the FAA.

**Dr Fuchs, Germany**

Do you consider the results of your investigations as real-task related - trends, or - more or less - as individual (and partly age related) variations?

**Author's reply**

I am unable to give a precise answer. The comparative study of the four groups investigated seems to establish that variations are rather individual than task related.

**Médecin Général Salvagiac**

1. In your statistics, have you differentiated between approach controllers working in control towers and regional traffic controllers?

2. Have you carried out a statistical study of the errors committed by the controllers?

**Author's reply**

1. The general statistics relating to Belgian Air Force personnel cover both approach and regional controllers.

   The detailed nosological statistics relation to Eurocontrol personnel apply only to regional traffic controllers.

2. No study has been made of the decision errors made by controllers. The present study has been limited to the nosological aspects.

# PSYCHOPATHOLOGY OF AIR TRAFFIC CONTROLLERS AND RADAR OPERATORS

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## SUMMARY

The activities of air traffic controllers and radar operators have,within the aeronautical sphere,particular connotations because of the enviroment in which they are carried out and because of their technical and operational content.
These connotations are such that they may give rise to a stress effect with consequent psychic pathology of variable intensity. On the basis of observations and personal experience, a general nosographic description of the syndromes and of the psychopathologic states most frequently noted, is submitted and considerations and proposals are formulated with the aim of preventing and containing them.

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In aviation medicine, when we speak problems of alertness, stress and psychic fatigue, we normally believe that these problems are specific only to pilots and aircrews. However, the procedural and technological characteristics of both military and civilian flights have long since reached such a level of complexity that other individuals on the round who monitor and supervise the conduct of fligts are also seriously affected by these problems.

Among these individuals, air traffic controllers and radar operators have a task of primary importance. Several authors have dealt with the physiological and physical effects of stress on this type of personnel (Melton,Mc Kenzie,Polis, Schwarz,Dreisback,Saldivar,Hale,William,Smith,Hoffman, De Cani,Funkhouser,Iampietro, Evrard,etc.).

Services concerned with aids to navigation have reached, during the last 20 years a large scale, in proportion to the considerable development of air trasportation. Present air traffic is such that it may be calculated that each day about one million passengers fly through the skies in an average of 8000 to 10.000 aircraft. These figures do not include military air traffic and private civilian traffic. Forecasts indicate that the total payload transported by air will almost triple in the next ten years.

The introduction,which is underway at present,of supersonic air transport and of aircraft with STOL/VTOL characteristics will radically change again the techniques and the control procedures. The variety of to-day's air traffic, which already affects the punctuality and regularity of the flights will worsen even further because of the introduction of these aircraft. Man will always remain the main element in an air traffic control system howhever technological improvements may develop.

This statement is based on examinations made during the last 10 years on these types of personnel, both healthy and affected by psychic syntoms. As well as the result of diagnostic measurements the study is also based on clinical-psychological interviews, i.e. interviews to verity directly some basic parameters such as:

a) environmental and technical operational conditions relevant to psychic stress;
b) the motivation for choosing this type of employment;
c) long term validity of present medical selection;
d) psychic exhaustion and saturation thresholds and their correlation with above.

Representatives of the category completely unaffected by any pathological condition were also interviewed to provide a control group.

The personnel who participated in the research included the following:

Airport controllers (TWR)
Approach controllers (APP)
Regional or area controllers (ACC)
Precision radar operators (GCA)
Approach radar/operators
Regional radar operators
Air defence Radar Operators (interception controllers).

ENVIRONMENTAL AND TECHNICAL OPERATIONAL CHARACTERISTICS WITH A SPECIFIC PSYCHIC REFERENCE

1 - Environment - The environment in which these personnel have to operate is represented by control tower operations rooms on or under the surface us a mobile trailer; all these environment entail close association among themselves with others operators (such as teletype operators, mechanics,etc.), whose number varies in accordance with the size of the site. For example, in the control tower of a large airbase there may be at any one time 10-12 controllers operating side by side, while in a small airbase, where air traffic is reduced, the number of operators may be limited to 2 or 3. An operator mustn't stay alone for security reasons; a substitute must be available in the event of sudden indisposition of the first. Necessity of close contacts may have repercussion on psychic equilibrium.

The control room of an average airbase,including the tower and approach services, entails the operation, perhaps not simultaneously, of 10 working frequencies which may be employed by 2 operators. To these must be added the telephone links with operational agencies of the base (operations room, fire prevention, medical center, ambulance service, etc.). In the other words, normally 3 to 4 frequencies and 1 or 2 telephones are operating simultaneously.

In some cases the control room also contains the air conditioning apparatus and this may increase the average noise level. More than the noise, it seems that what affects the nervous system is the continuous operation of the receiving and trasmitting devices which is often less than perfect because of weather conditions, interference, etc.. The fact that radar operators must work in darkness or in dim light, although tiring, does not seems to have any particular importance from a psychic point of view.

There is no doubt that there are great differences between airports with intense and continuous traffic and airports where the traffic is limited. Nevertheless in the latters receivers are always in operation, as well as all the other noises.

However, we should note that from the point of view of alertness and therefore from point of view of security, those operators and controllers who work less continuously represent the greatest danger because the discontinuity gives rise to the possibility of lack of concentration. In order to avoid this, various methode and procedures are applied (calls, requests for checks, tests,etc.).

2 - Operations - From the point of view of stress originating from their work, excluding physical risk, we suggest that the air traffic controller is more exposed than the pilot.

The pilot knows his position and situation, and is also aware of the situation and position of others which are operating on the frequency he receives. However he is often not aware of all those who are, because of reception, on his frequency, furthemore because the conduct of the aircraft requires great concentration of superior psychic processes.

The air traffic controller has to concentrate on a much wider range of activity. He must visualize the aircraft in the air space calculate the separation between them and the separation that will result as a function of various parameters (destination,height,transfer from one sector to another,etc.). All this, from point of view of alertness, concentration and stress, reaches a peak in poor weather conditions, unforeseen increases of traffic, difficulties with radio aids and radio communication,etc.

However there is one phase in particular which generates anxiety. This phase can be divided into three sub-phases:

a) - during the preparation of the instructions which must be passed to the pilot;

b) - during the issue of these instructions because the controller is talking to someone he cannot see, and thus is unable to assess, through facial expression, how well the instructions are understood;

c) - when he has to verify that the pilot has followed, in the right way, all instructions.

The activity of radar operators differs from that of air traffic controllers since the latters base their work on positions reported by pilots (and the controller must take into account the possibility of pilot error in his reporting). On the contrary, a radar operator works on accurate visual representations.

The work of the controller is more stresfid from the point of view of involvement and psychic fatigue in the long run. In radar operator the stress effect may assume a more acute and immediate character because of the fact that he can suddenly visualize a possibly anomalous situation which comes about or which may come about because of an error on his part. Anxiety in the controller builds up gradually, because a pathological component is created and developed by the projection of an anomalous event; on the contrary, the radar operator suffers from other anxiety more directly and immediately.

For a radar operator in the air defence system (vectoring on intercept) it appears that his responsability, instead of maintaining a separation between aircrafts as is done by the air traffic controller, is to vector his fighter onto a collision course with the target. The psychopathogenous factor in this case is more limited, since the operator controls only two aircrafts at any time and also because the situation is generally more "limited".

3 - Limits - A saturation level as average appears between the 5th and 8th years of activity with the same responsability and in the same location. This situation is generated both by a lack of stimulus because of the tedious uniformity of the job (as happens in many types of activity) and by actual psychological weariness.

From a pathogenetic point of view, observations and examinations which have been carried out, suggest that the psychostressing effect is, in most cases (as happens in other areas of work) directly proportional to the "discontent index" of the subject towards his job and towards the environment in which it takes place. On the other hand discontent must be interpreted in turn as a direct consequence of the degree of fatigue and psychic commitment and of the problems connected with this type of activity, which may not have been fally foreseen by the subject concerned. In this respect, it is important to recall that persons in this profession are volunteers.

Sometimes, the very fact that a certain type of work is identified as a factor of anxiety, may give rise to reject and refusal mechanisms which in rare cases take the form of obsessive phobic conditioning.

## NOSOGRAPHIC CLASSIFICATION

The psychopathological syndromes more frequently met may be nosographical classified as follows:

A. - Neurotic syndromes of the dysforic and neurasthenic type

These are marked by a general characteristics of discomfort as in all neurothic syndromes which induce in the subjects a mood which is generically unpleasant.

A1 - Reactions of anxiety

These are reactions to events which are either objectively dangerous, although the degree of danger may be relatively small, or represent for the subjects a particular commitment expecially in the field of decision making.

A2 - Secondary anxiety phobiae

These are detected after emotionally stressed events which cause in the subjects a reaction greater in intensity and longer in duration than normal.

A3 - Psychosomatic equivalents of anxiety

These represent a conversion of the state of anxiety, and the range of symptoms may be extremely variable, affecting a variety of systems: pseudo-vertigo crisis, perspiration, restless legs, tachycardia, gastro-enteric disturbances, cutaneous itching, etc.

A4 - Neurasthenic type syndromes

x) Psycho-physic asthenia - is characterized by an annoying feeling of tiredness in the muscles and in the brain after any type of activity, sometimes associated with psychesthenia and with a background of alarm, and rarely with hypocondria notes and still more rarely with phobic symptoms.

y)Hyperesthenic-emotional asthenia - is characterized by a state of ill-humored irritation with psychastenia (in particular the "tirage nucale" and the "sense of void in the head"), and in some subjects, also with hypochondriac attitudes.

z)Alert neurasthenia - is characterized by association with the prevailing aspect of the psycho-physical asthenia of alert episodes which are lived as unpleasant feelings of lack of health.

B. - Dystimia

The term "dystimia" in Italian, covers the maniac-depressive psychosis, in the strict sense of the word, and is the equivalent of both the terms "cyclothymia" and "maniac-depressive circle" (manish-depressiver Formenkreis) utilized more frequently by german authors. Typical syndromes are seen, and may be classically characterized by the following main elements: vital sadness; inhibition or alteration of the activity; inhibition or alteration of the consciousness of reality (for the depressive syndromes); and euphoria, psychomotor exitement and disinhibition (for the maniac syndromes). Also atypical symptoms are seen which cannot be broken down into these three elements and which differ from the previous ones because of their clinical characteristics (modality of exordium, psychopathological connotations,etc.).

The following classification, is related to "atypical syndromes" which are characterized according to the predominant atypical psychopathological element:

B1 - Depressive background and prevailing anxious element

Characterized by a prevailing almost continous anxious restlessness with depressive thematics (ideas of ruin, of guilty, hypocondria).

B2 - Depressive background and elements of a neurotic nature

Characterized by the presence of prevailing symtoms of the ps choneurotic type which may be both of the alert and/or of the hypochondriac type.

B3 - Manic background and the prevalence of irritability elements

Characterized by exaltation of temper, prevailing irritability and hostility during which the subjects appear querulous, polemic and revengeful.

CONSIDERATIONS AND PROPOSALS

From these results, certain considerations and proposals arise:

1. Selection

In addition to physical psychometric and psycho-attitude types of selections, extreme importance to carry out a "selection on the job", that is to say a selection process conducted during a period of "on the job training" by a team of selectors qualified professionals.

The most important elements to be assumed during such a selection process should be speed of reflexes and ability to reach decisions. From the point of view of character, special care should be taken to ascertain that the subject possesses and adeguate degree of extroversion. Situations which the operator will meet with charge rapidly this entails a requirement for remarkable ability, imagination, and improvisation. It's necessary for radar operators to imagine positions tri-dimensionally, taking into account altitude, distance,(both lateral and longitudinal) and time.

2. Mental Hygiene

No operator should be employed for more than 8 hours, with relief breaks of an average duration of about 15 minutes every two hours.

Use of relief time should not be left entirely to the discretion of the operators but should be pre-planned according to specific rules. This period of time should, for example, be used to re-examine what has taken place during the precious hours of duty, or to consider the situation which the operator may have to cope with when be goes back to work. The relief period should take place in an environment of soft suitable background music or should be characterized by a light and tonic physical exercise.

In addition to being extremely useful from a technical and professional point of view, all this could represent a valid system to maintain a high degree of concentration. The fact that the individual remains psychically connected with the professional environment does not deprive the break of its validity as a true recovery period, because the subject is not called upon to reach decisions.

The break should take place in premises adjacent to the work site; although comfortable, they should not be distracting nor deconcentrating in so far as recreational installations are concerned. An excess of the latter, or a wrong selection of them, could give rise to stimulating situations capable of activating problematic and conflicting situations capable of disturbing that psychic equilibrium which should be maintained at an optimum level.

Furthermore it is advisable to let the controllers interrupt their activity at certain intervals -in general for not more than a month(20-40 days)- taking into account that on the basis of what has been said before controllers suffer from psychical stress before radar operators.

### 3. Utilization of time

It has been noted that individual saturation level is reached, an average, between the fifth and the eighth year of acticity in the same branch and in the same location. In order to prevent such a phenomenon, it would be advisable within the time limits indicated above to transfer the individual from one control area to another, that is to say from the traffic control to the radar control. Such a transfer would be reincentivating since the controllers would have to requalify in the new position by mastering new procedures; eventually they will find new sources of interest in their new activities.

The operating life of the controllers may be estimated at about 20 years. A longer period of activity is not advisable not only for physio-psychical reasons, but also because incompatibility situations may arise between the senior controller and the junior aid who is completing his on the job training. Having just completed his studies the latter is inevitably full up to date and this could cause difficulties and uneasiness in the senior.

The next problem is how to make use those personnel later on, without wasting the experience they have acquired, taking care that the individuals don't feel that their professional life is finished at a relatively early age. In order to do this it is advisable to plan and establish their re-integration in the field by employing them for example in the programming and updating of procedures, in activities connected with the selection of personnel as in inspection and evaluation teams, permitting them to maintain the allowances they had previously enjoyed.

In conclusion, the activity of air traffic controllers (as well as other aeronautical activities), entails a psychopathology of a specific nature, the influence and effects of which, once known, may be contained by means of certain actions and corrective measures. The present contribution is necessarily a brief summary, is intended to be a simple contribution in the complex field of flight safety,which represents a priority commitment for all those who, at various levels, operate within the aeronautical area.

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# USAF EXPOSURE STANDARDS FOR RADIOFREQUENCY/MICROWAVE HAZARDS CONTROL

by

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## SUMMARY

Current research on the biological consequences of man's exposure to nonionizing (radiofrequency/microwave) radiation fields provides new guidelines for personnel safety. The effects of radiofrequency radiation on the nervous system, behavior, and the eye, and such indirect biological effects as cardiac pacemaker interference are discussed in terms of their impact on setting appropriate personnel exposure criteria for operational RF emitters. The information presented supports a careful balance between personnel safety and operational constraints. Of primary importance is the recognition that radiofrequency (10 kHz - 300 GHz) radiation insult to man is strongly frequency dependent. Thus, all bioeffects data generated in the laboratory using smaller animals must be carefully scaled/extrapolated to equivalent effects on man before meaningful exposure standards can be established. This frequency dependent concept is reflected in United States Air Force Regulation 161-42, which establishes a 50 mW/cm$^2$ permissible exposure limit (PEL) for radiofrequencies from 10 kHz to 10 MHz and retains the previously established 10 mW/cm$^2$ PEL for radiofrequencies from 10 MHz to 300 GHz. Further divisions of these spectral regions are anticipated as research data becomes available.

## INTRODUCTION

Radiofrequency (RF) radiation is defined herein as that portion of the electromagnetic spectrum between 10 kHz and 300 GHz and includes microwaves. Figure 1 illustrates this definition. Radiofrequency (RF) radiation is often described as nonionizing, and thus is thought to be nonhazardous. In fact, however, RF radiation can be hazardous to man; and safety standards must be applied for all RF systems operations. The "10 mW/cm$^2$ safety level" (used in most U.S. standards today) was originally established as an acceptable acute thermal burden on the basis of research performed from about 1955 to 1965.

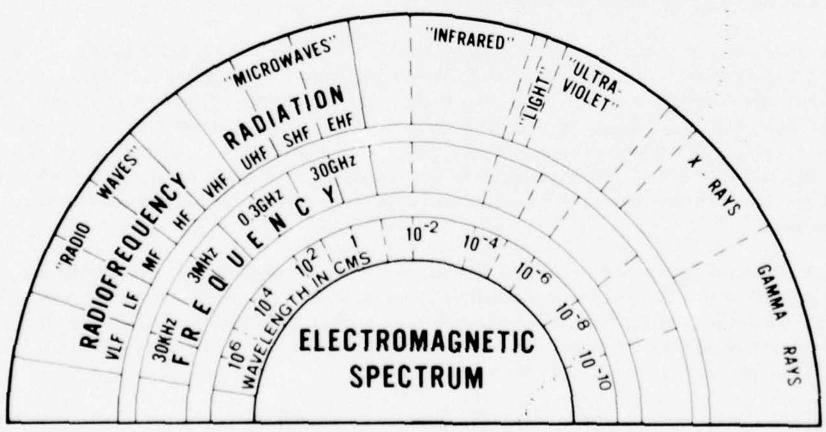


Figure 1. Frequency spectrum of electromagnetic radiation.

Today such standards are being seriously challenged, primarily because the Warsaw Pact countries report standards lower than 10 mW/cm$^2$; and, in the United States, recent congressional legislation focuses more attention on overall environmental quality and personnel safety. Public Law (PL) 90-602, the Radiation Control for Health and Safety Act of 1968, gives the Department of Health, Education and Welfare (DHEW) the authority to issue emission performance standards for electronic products. This Law resulted in a 5 mW/cm$^2$ emission standard for new microwave ovens, thus implying that the 10 mW/cm$^2$ level was not adequate.

PL 91-190, the National Environmental Policy Act, requires Federal Agencies to assess all actions which have an impact on environmental quality, including the consequences of exposing the general populace to any EMR emitted by operations of the Department of Defense (DOD). Executive Order 11752 further requires Federal Agencies to be consistent with Federal guidance on radiation and applicable environmental radiation standards promulgated by the Environmental Protection Agency (EPA). PL 91-596, the Occupational Safety and Health Act of 1970, authorizes the Department of Labor (DOL) to promulgate health standards for workers exposed to EMR. Executive Order 11807, 28 September 1974, requires Federal Agencies to issue safety and health standards consistent with those promulgated by DOL.

At the present time the Occupational Safety and Health Administration (OSHA) has adopted the values used in American National Standards Institute consensus standard C95.1-1974, "Safety Level of Electromagnetic Radiation with Respect to Personnel." This standard covers the frequency spectrum from 10 MHz to 100 GHz, and essentially permits unrestricted continuous wave exposures of 10 mW/cm$^2$ and a 3600 mW-sec/cm$^2$ exposure averaged over any 6-minute period.

In response to this national and international concern to maintain appropriate safety standards, the U.S. Air Force is conducting a research program designed to achieve a careful balance between personnel safety and unnecessary operational constraint. The importance of this concept may be illustrated by considering the impact of reducing the existing 10 mW/cm$^2$ standard by a factor of 10 (i.e., to 1 mW/cm$^2$), thus increasing the radius of the controlled perimeter around RF emitters by a factor of ~three. If such control should become necessary to achieve adequate personnel safety, it would be appropriate. If such limits were imposed just to achieve "greater safety," however, they would not be appropriate.

## PHYSICAL CONSIDERATIONS

RF energy deposition in any biologic system is strongly dependent on the geometric size of the subject and the frequency of the incident radiation. This is best illustrated by the curves shown in figures 2 and 3. These curves were generated by Mr. S. J. Allen at the USAF School of Aerospace Medicine (USAFSAM) to assist experimenters in interpretation of empirical studies using monkeys and rats and subsequent extrapolation to equivalent effects in man (1).

The data points for these curves were generated using three different methods covering three frequency ranges. For the situation where the human subject is short compared to the wavelength of the incident RF radiation (1-50 MHz), both theoretical power absorption calculations by personnel at the University of Utah (2) and empirical measurements made at USAFSAM were utilized (3, 4, 5).

For the second situation where the size of the human subject (small child to large man) approaches resonant conditions (50 MHz - 500 MHz) the data points were approximated by assuming equal capture aperture for man and animal, i.e., computing the frequency which resulted in the same wavelength to subject length ratio. Resonant conditions are most likely to occur when the length of the irradiated subject is $\sim 0.4\lambda$ (wavelength of incident radiation).

For the third frequency region (0.5 - 100 GHz) where the human subject is large compared to the wavelength of the incident RF radiation, data of Johnson and Guy which gives penetration depth as a function of frequency for muscle and skin were used (6). Using elliptical cross sections, calculations were performed to determine the ratio of radiated to nonradiated volume as a function of frequency for man, monkeys, and rats. For frequencies greater than 500 MHz these data were used to determine the frequency for the animal which gives an equivalent radiated to nonradiated ratio. For frequencies greater than 10 GHz, the penetration depth (~3 mm) is so superficial that extrapolation would not generally be required.

Based on these physical considerations, it becomes apparent that direct extrapolation of RF radiation effects obtained using animals in laboratory studies is rarely acceptable for setting safe personnel exposure criteria. For example, using figure 2, it can be seen that a 5500 MHz exposure of a rat would be equivalent to a 500 MHz exposure of man. These data assume subjects are exposed with their long axis parallel to the E-field vector, a worst case situation.

Thus meaningful interpretation of any biologic response resulting from RF radiation exposure requires detailed knowledge of the quantity and distribution of the RF energy in the organ or bio-area being studied, and dynamic analysis of the subjects' ability to dissipate the energy through normal thermoregulatory processes.

Because of the overall importance of energy distribution and measurement assessments in defining the biological consequences of man's exposure to RF fields, an "RF Researcher's Guide" containing the pertinent extrapolation data is being developed under AF contract. A first draft of this handbook should be available in September 1976.

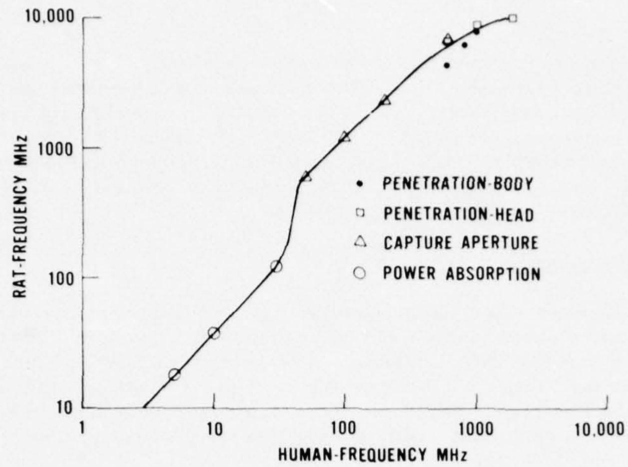


Figure 2. RF radiation frequency extrapolation, rat to man.

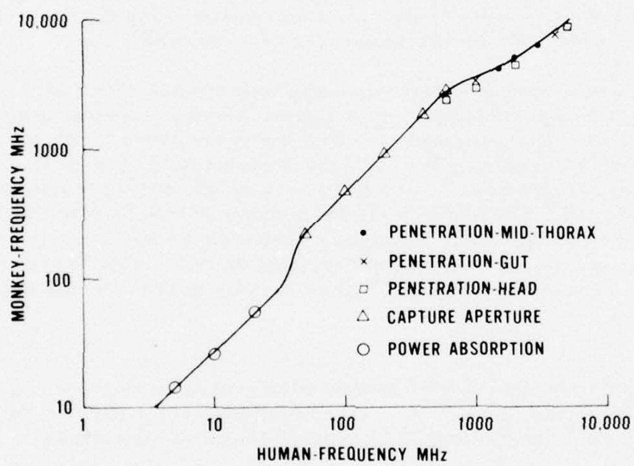


Figure 3. RF radiation frequency extrapolation, monkey to man.

## BIOLOGICAL EFFECTS CONSIDERATIONS

### Nervous System

A large portion of the RF bioeffects literature deals with reported effects on the nervous system. Such data are often cited as the basis of the reported exposure standards of the Warsaw Pact countries. Certain measurable changes in physiologic response, neurochemistry, and morphology are clearly identified with RF exposure, but generally lack sufficient detail on which standards can be based. The principal question, as to what magnitude of changes are clinically significant, must be resolved before such data can be used to adjust current RF exposure safety criteria.

### Behavior

Like nervous system effects, behavioral effects resulting from RFR exposures are often reported in the literature of this subject. Reported effects include a wide variety of responses ranging from a "general irritability syndrome" to significant changes in functional performance. Animals and man can detect RF radiation fields at levels far below that which seems to alter behavior. Again, a more definitive position is required to assess the clinical and/or functional significance of such effects as a function of the RF radiation exposure profile prior to adjustment of RF exposure criteria.

### Ocular

The fact that microwaves can produce lenticular opacities of the eye has been known for over two decades (7). In any general assessment of the biologic effects of EMR fields, the eye is often identified as the principal organ of concern. However, the bulk of available experimental evidence supports the position that RF radiation exposures greater than 100 mW/cm$^2$, for periods longer than an hour, are required to produce lens opacification. While this position is accepted for acute exposures, questions remain concerning possible changes in the injury threshold due to intensely pulsed fields and the cumulative effects of fractionated longer term exposures.

### Cardiac Pacemaker Interference

One unique aspect of RF effects on man is the effect on cardiac pacemaker performance. In 1970, the USAF recognized that some pacemakers could be seriously disrupted by pulsed RF sources. Tests revealed the most sensitive devices had interference thresholds less than 10 V/m, while fields of several hundred V/m were possible for certain high-powered pulsed radar systems. The minimum electric field intensity associated with the acceptable 10 mW/cm$^2$ average power density is ~200 V/m, while pulsed systems with short duty factors can significantly exceed this level without exceeding the 10 mW/cm$^2$ average power density.

From 1971 to 1974, the Air Force conducted a series of pacemaker tests in the laboratory and at numerous AF RF emitter (radar) sites (8, 9). The results showed that, although many pacemakers in use had low (~10 V/m) interference thresholds, it was technically feasible to design and manufacture pacemakers which would be compatible with the unrestricted RF environment (200 V/m). Based on these empirical data, the AF recommended that the U.S. Food and Drug Administration (FDA) request the manufacturers to develop and adopt a pacemaker electromagnetic compatibility (EMC) performance standard of 200 V/m using a 450 MHz square wave pulse of 1 ms width, and applied at a rate of 1-5 pps.

Many manufacturers now recognize electromagnetic interference (EMI) as a potential problem, and include this parameter as a design consideration in all new devices. Several manufacturers have essentially solved the problem (10). Thus, instead of 80% of the pacemakers in use having EMI thresholds of 10 V/m (as was the case in 1970-1972), only ~20% have thresholds of 10 V/m. Of significant importance is the fact that ~50% of those pacemakers in use will now meet the 200 V/m criterion as recommended by the Air Force to the FDA in 1973. Essentially all pacemakers should be compatible with pulsed fields of at least 200 V/m by 1977-78, a significant technologic advancement and a relatively fast solution to an RF bioeffects problem. Also, the newer pacemakers seem more reliable in many respects, are smaller in size, and even with standard battery supplies, some are now guaranteed for 6 years.

## DISCUSSION

Development of RF radiation exposure standards is an evolutionary process. While most standards or guidelines used today are based on estimates of an acceptable acute thermal burden, it is well recognized that many other factors (both physical and biological) require consideration.

Specific biological consequences of RF radiation exposure clearly depend on: (1) the frequency of the incident radiation and, therefore, its physical distribution in the subject, (2) the intensity and time of the exposure, (3) the state of health of the subject, (4) the exposure geometry (configuration of subject with respect to RF source), and (5) environmental conditions. More subtle modifiers include: (1) the effect of possible frequency resonant conditions on overall RF energy transfer and distribution, (2) the effect of fractionated exposure profiles for both short and long time periods, (3) the effect of pulsed modulation versus continuous wave exposures, and (4) the biological significance of "hot spots" or "weak link organ or bio-area" considerations.

Considerable national and international interest is apparent at this time to resolve some of the more pressing questions and to apply the research findings to modify existing RF exposure standards. However, the complexity of the tasks makes it a slow process.

Progress in this area is generally enhanced by research organizations that apply a multiple disciplinary team approach that includes physicists, electrical engineers, veterinarians, and mathematicians, in addition to the biological research specialists (physicians, physiologists, chemists, biophysicists, and behavioral scientists). Accomplishment of meaningful research and extrapolation of the research data obtained from animals under laboratory conditions to man in real world operational situations requires diligent efforts from all these specialties. The final, but most important, step is the application of the research findings to adjust personnel exposure standards to achieve a reasonable balance between personnel safety and operational constraint.

## USAF RF RADIATION STANDARD

In November 1975, the USAF published a new RF radiation standard, Air Force Regulation 161-42, titled Radiofrequency Radiation Health Hazards Control (11). It supersedes Air Force Manual 161-7 (December 1965). It establishes Air Force policies, assigns responsibilities for carrying out these policies, provides RF exposure standards for personnel (these may be defined as interim standards based on the information presented in the Discussion section above), and establishes a surveillance program for the protection of personnel working with or in the vicinity of RF radiation emitters.

Figure 4 summarizes the USAF permissible exposure levels (PEL) for Air Force personnel. The 50 mW/cm$^2$ PEL for RF emissions in the 10 kHz - 10 MHz frequency range is based on both theoretical and empirical data, and sets a precedent for RF exposure criteria based on a frequency dependent approach. This higher level is appropriate since these PELs are based on the acute thermal burden concept and RF energy deposition in man decreases with the square of the frequency below ~30 MHz. The fixed value was applied rather than a variable as a function of frequency since it is easier to apply operationally.

| | FOR FREQUENCIES 10 MHz - 300 GHz | FOR FREQUENCIES 10 KHz - 10 MHz |
|---|---|---|
| EXPOSURE TIME GREATER THAN 6 MIN (360 SEC) | 10 mW/cm$^2$ | 50 mW/cm$^2$ |
| EXPOSURE TIME LESS THAN 6 MIN (360 SEC) | 3,600 mW - SEC/cm$^2$ | 18,000 mW - SEC/cm$^2$ |

NOTE: ALL EXPOSURES LIMITED TO 100 KV/M MAXIMUM PULSED E - FIELD LEVEL

Figure 4. RF radiation permissible exposure levels (PEL) for personnel.

The 10 mW/cm$^2$ PEL for RF emissions in the 10 MHz - 300 GHz frequency range is consistent with the U.S. Occupational Safety and Health Act of 1970. For exposure times of 6 minutes or less, the PELs are adjusted to allow higher power densities, but exposures cannot exceed the time averaged PEL values shown in figure 4 for the respective frequency ranges. Figure 5 displays the same data as figure 4, illustrating the permissible time-power density combinations for the respective frequency ranges.

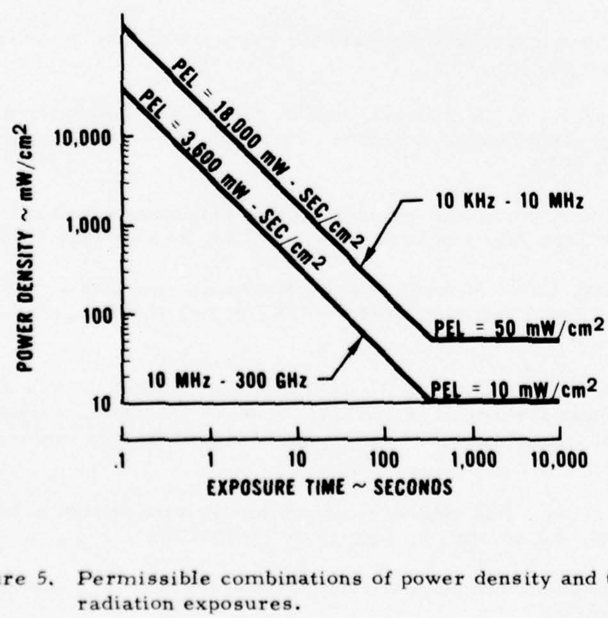


Figure 5. Permissible combinations of power density and time for RF radiation exposures.

Figures 4 and 6 document one additional RF exposure limitation, viz., that single pulses of RF emission to which personnel may be exposed shall not exceed an electric (E) field level of 100 kV/m. This would apply to electromagnetic pulse (EMP) generators. Figure 6 provides in graphic format combinations of duty factor and E-field levels that are permissible for the frequency ranges covered by AFR 161-42.

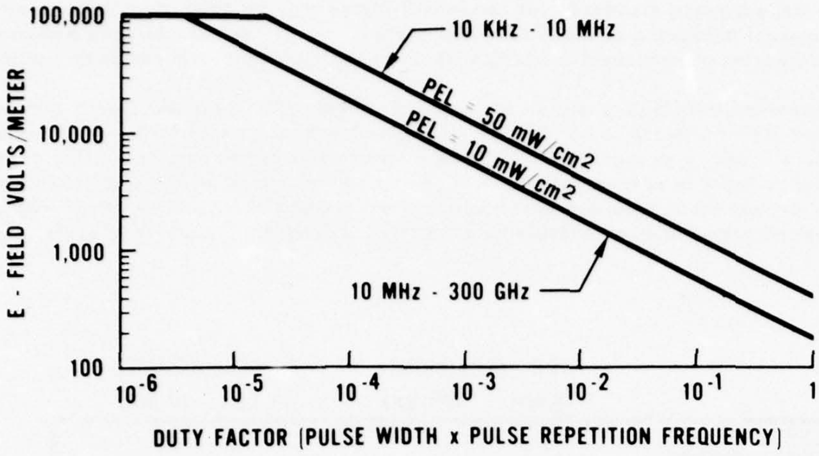


Figure 6. Permissible exposure levels for pulsed RF emission.

In summary, the USAF RF exposure standard establishes permissible exposure levels for personnel exposed to any RF emission in the 10 kHz - 300 GHz frequency band. It sets policies and assigns responsibilities for RF hazards control. The regulation presents general information on the nature of RF electromagnetic radiation and discusses the categories and impact of biological effects including such indirect effects as cardiac pacemaker interference.

Special guidance is provided on actions to be taken for a suspected overexposure (defined as two times the PEL), to include medical examinations and clinical follow-up. On the other hand, routine pre- and postemployement medical examinations are not appropriate and the reasons for this position are discussed (11).

An official RF Hazards warning sign is specified and guides are provided for implementing a Base Level RF Personnel Protection Program and for Surveying Microwave Ovens. The new regulation also provides useful equations and numerous examples for calculating PEL hazard distances.

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# BIOEFFECTS RESEARCH IN THE DETERMINATION OF LASER HAZARDS

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## SUMMARY

A summary of the endpoints used in the establishment of ocular damage threshold levels from laser exposure includes the evaluation of grossly visible retinal opacity, photoreceptor alteration at the level of the light and electron microscope and functional alteration in the task oriented animal subject.

The threshold determination at the light and ultrastructural levels extends the sensitivity and reduces the threshold level for all laser wavelengths. The behavioral evaluation of laser exposures are one thousand times below the visible lesion endpoint and demonstrates changes which must be taken into account in the evaluation of permissible human levels.

A review of the research in the area of retinal effects from laser radiation will provide, at low levels, a comprehensive review of the function of the retina and central nervous system interconnections as applied to "normal" ambient light-level exposures.

## INTRODUCTION

The immediate hazard associated with laser radiation in the field is the possibility of sudden loss of vision, glare, subtle inability to clearly focus or the distraction from an assigned mission by the perception of the radiation as an environmental change (e.g., warming of the skin, brightness of the working area). In the military scenario these changes may produce altered ability to complete missions which require the full use of the intact visual system.

The present and projected uses of laser systems has resulted in the full cooperation of all NATO nations into the research of the biomedical hazards of laser radiation. These hazards extend from the direct impact or laser irradiation on the cornea, lens, and retina of the eye (1-5) or skin (6-8) to the hazards from toxic lasing media and associated high voltage electrical equipment (9).

The actual hazard associated with a laser exposure from a simple laser source is statistically minimal, but the hazards are far greater from current and projected field utilization of a multiplicity of laser systems. The immediate effect in establishing safe levels for field exercises is to adhere to one or more of the current safety regulations (10-12) or to establish the most conservative approach to the field use of laser devices and systems where data is not yet available.

Research by investigators in England, Europe, Canada, and the United States has been directed toward establishing a broad-based approach to the understanding of the biological effects of pulse width, wavelength, and pulse repetition rate using criteria for tissue alteration involving observation of the tissue by routine clinical techniques (slit lamp biomicroscope, direct and indirect ophthalmoscope, fundus camera) or histological analysis (light, electron microscopy). These data are available as a base from which member countries can extrapolate to safe operating levels for human exposure using factors to account for atmospheric effects, macular sensitivity, animal variability and human tissue variables.

## OPHTHALMIC MORPHOLOGY

The eye is the most sensitive end organ and is the most vulnerable to laser exposure. Light is sharply focused onto the retina. When an object is directly viewed, the image falls on the fovea centralis of the macula. This central area, approximately 250 $\mu$ in diameter (humans) has a high density of cone photoreceptors (color sensors). Recent research in the protein synthesis of the photoreceptors by Young (13) shows that the cone does not turn over (renew) protein in a continuous manner as do the rods (contrast sensors). The cone photoreceptor is a highly specialized light reactive cell. Therefore, sufficient alteration of these photoreceptors as by a laser source may be permanent.

## OPHTHALMOLOGY NEUROANATOMY - PHYSIOLOGY

The complexity of the retina involves multiple links between photoreceptors (rods) at the level of the biopolar cell layer and further complexity in the neuroanatomical structures between the retina, lateral geniculate and visual cortex. Some measure of the effects of laser light on these structural connections can and are being addressed using behavioral and electrophysiological techniques. These approaches are necessary in the evaluation of low level subthreshold laser exposures where no direct evidence of retinal alteration exists.

## EXPOSURE CONDITIONS

Each of the lasers of interest is set up and carefully evaluated to determine pulse width, spatial distribution of the laser beam (Figure 1) and exact dosimetry required for exposures of primate eyes.

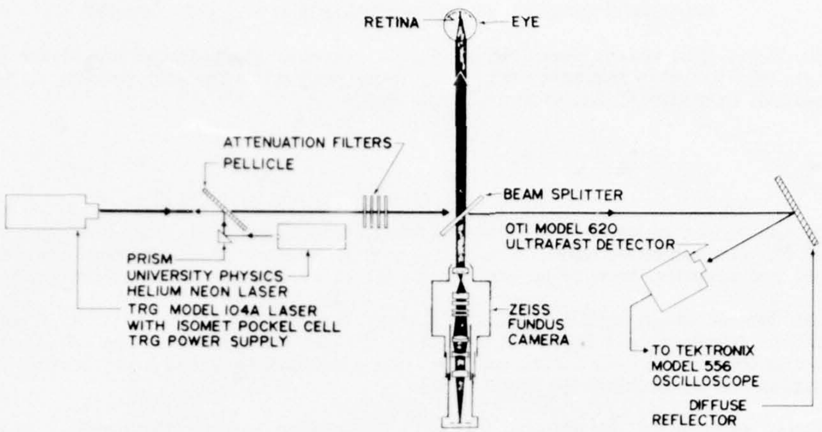


FIGURE 1. Typical laser exposure system. Fundus camera is positioned for viewing retina before and after laser irradiation and is coaxial with the helium-neon alignment laser and exposure laser.

Experiments are then conducted for the emmetropic, dilated eye (simulating the nighttime exposure condition) in the anesthetized primate for small retinal beam diameters (40-50 μ) and large retinal beam irradiance diameters 500-1000 μ. Sufficient exposures are made in the macular and paramacular retinal areas, and observed by funduscopy using the fundus camera and direct ophthalmoscope. The presence or absence of a visible retinal opacity is noted at 1 hour and 24 hours after exposure (Figure 2).

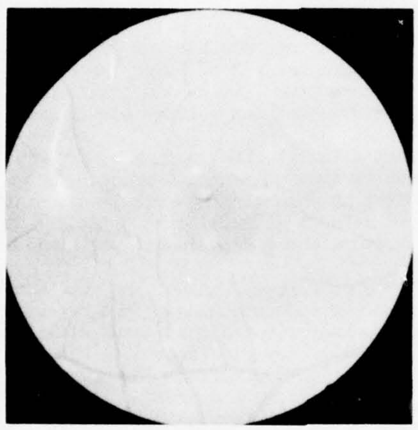

FIGURE 2. Retinal photograph 1 hour after exposure to argon laser radiation 1 second, 50 μ retinal irradiance. Appearance of vessel crossing through lesion (middle row, second from right) indicates depth of alteration.

These data are used to determine the "statistical" threshold referred to as the $ED_{50}$. Within 24 hours after exposure, histology of the exposed retina is analyzed by flat preparation (Figure 3) serial microscopy or ultrastructural evaluation.

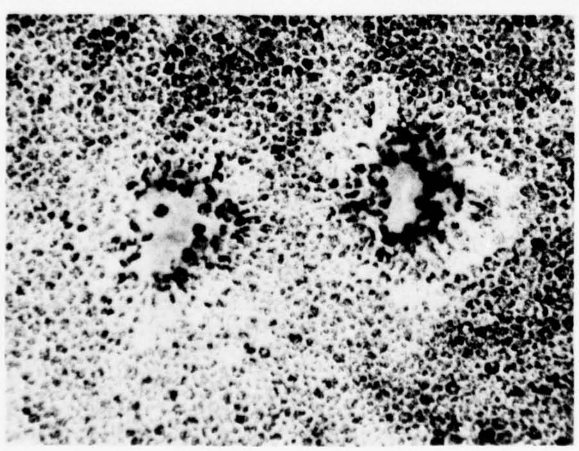

FIGURE 3. Flat preparation of Q-switched ruby exposure; 50 μ retinal irradiance at twice threshold level; 60 μj TIE (total intraocular energy). Pigment epithelial cells are displaced from lesions center with zone of darkly pigmented cells surrounding central area.

DIRECT OBSERVATION DATA

Threshold data, from which present safe levels have been derived, involve the use of primates. Data for Q-switched ruby (694.3 nm), neodymium (1.06 μ), frequency doubled neodymium lasers (530 n), continuous wave and mode-locked neodymium (1.06 μ), argon (488 nm), helium-neon (632.8 nm), and gallium arsenide (900 nm) have been obtained. The data indicated: (1) The retina is the tissue most affected by these laser wavelengths; (2) The thresholds for retinal alteration are lower for ultrastructural analysis by a factor of ten than for direct clinical observation; (3) The short pulse durations ($10^{-8}$ sec) required higher energy inputs than millisecond or second exposures; (4) The thresholds for small retinal irradiance diameters (40-50 μ) are many factors higher than for larger irradiance (500-1000 μ); (5) The thresholds for retinal alterations by direct observation (opacity) for Q-switched pulse are lower in the green (530 nm) than in the red laser wavelengths. These conclusions are based on review of most currently available data.

LIMITATIONS OF DIRECT OBSERVATION

The techniques for biomedical hazard research involve a structured, precise experimental laser dosimetry system with a carefully controlled animal subjects. The conditions for laboratory exposure impose the restrictions of anesthesia or analgesia, pupillary dilatation, careful correction of the refraction of the eye, and exact placement of laser exposures. These conditions are "ideal" and create laboratory experimental data for the "greatest hazard" level determinations. The data generated does not include the studies of retinal recovery (single sample) or the impact of retinal alteration or the ability to see.

FUNCTIONAL CRITERIA

Different techniques are required to assess the effects of various laser sources on the visual process itself. What happens to the ability to "see," to resolve small detail when exposed to levels of laser irradiation deemed "safe" by morphological criteria? We have employed various functional criteria to assess these kinds of effects (14). The immediate effects of foveal irradiation at suprathreshold levels produce profound changes in overall visual acuity (15,16). Long-term follow-up from six months to several years post-exposure, however, demonstrate that recovery in overall visual acuity does occur, but significant alteration in photopic spectral sensitivity persists. Several investigations currently in progress indicate that exposure to either brief or chronic visible laser irradiation can produce permanent effects in function at levels ten times below the safe level based on present standards (17). Such effects appear to be non-thermal in origin (18,19).

MECHANISMS

In recent years, an increasing amount of data has accumulated to suggest that mechanisms other than thermal are associated with the deleterious effects of light. Several mechanisms have been proposed that involve permanent alteration to the biochemistry and photopigments of the retinal receptors. In lower nocturnal animal species good agreement between the action spectra for these effects and the photopigment absorption spectra of the rod photoreceptors has been obtained (20). However, in more recent work in the rhesus monkey, less agreement between the action spectrum and photopigment absorption spectra is apparent (21). This area of work is currently very active and more definitive answers may be available soon.

SKIN AND CORNEAL LASER ALTERATIONS

Alterations of the skin are produced by laser exposure varying from third degree burns to subtle erythematous alterations of the dermal vessels (Figure 4).

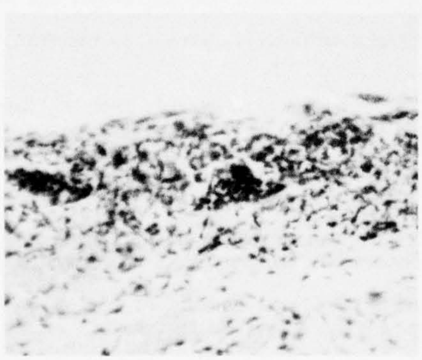

FIGURE 4. Section of porcine skin, 24 hours after TEA laser exposure. Normal architecture of skin is destroyed with evidence of charring (250 ns, 2 j/cm$^2$).

The accidental exposure to infrared laser radiation produces a sensation of warmth which may result in "reflex withdrawal" which can be a greater hazard than the incident laser exposure (22). Similarly, the effects of this laser radiation can produce subtle clouding of the cornea proceeding at higher exposure levels to permanent corneal scarring or corneal penetration (Figure 5).

FIGURE 5. Corneal opacity photographed 1 hour after exposure to carbon dioxide laser radiation (100 ms, 65 w/cm$^2$).

DISCUSSION

The impact of these research studies is to reduce the safe operating laser levels, while the field exercise is to successfully use the laser devices and systems. The requirements of the use of lasers involves a closely coordinated program involving education of the user and his commander in the area of laser hazards, careful review of the field exercise by a trained individual in the potential hazards of the laser system to be used, and appropriate protective measures to insure a safe, mission effective, tactical scenario.

The recurrent emphasis on the associated hazards of laser radiation have recently been reported in the press in the United States. These incidents have been associated with two deaths by electrocution in individuals working with high voltage laser power supplies used in laser systems. Such reports are a warning to the laser user and could easily occur in the field maintenance or use of a laser device. Likewise, the chemical and noise level hazards associated with gas and chemical lasers could be completely understood and precautions taken to avoid chronic exposures.

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NOTE

In conducting the research described in this report, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care" as promulgated by the Committee on the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Academy of Sciences - National Research Council.

# THE ATTENUATION EFFICIENCY SCORE
# A MEASURE OF OVERALL HEARING PROTECTIVE EFFICIENCY OF HEARING PROTECTORS

by

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SUMMARY

The Attenuation Efficiency Score (AES) is a new method for an overall description for sound attenuation characteristics of hearing protectors with a single value. The derivation of the AES will be presented with emphasis on the reasons why the AES is an unbiased estimate of the overall attenuation of a hearing protector. Comparisons of this method will be made with other methods that express overall attenuation in a single decibel value. The AES is presented as an unbiased overall measure of the relative attenuation efficiency of hearing protectors within the limits of the known state-of-the-art. The normalization of low and high frequency attenuation values into percentiles eliminates high frequency biasing of overall evaluations that occur with averaged decibel values.

Military training and operations have been a source of hazardous acoustic environments since the invention of gunpowder. Histories of warfare or medicine have not recorded the extent of hearing loss due to hazardous acoustic environments on personnel, but it may be safely speculated that the high impulsive noise generated by weapons caused losses of hearing. Limited hearing protective procedures have been practiced in the past -- such as the use of cotton as earplugs, but until the early 1950's there existed few efforts to quantify acoustical hazards or attenuation characteristics of hearing protectors.

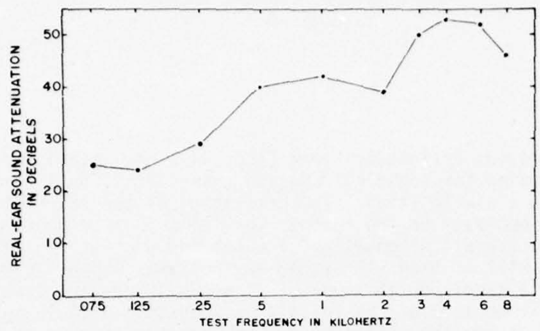
The introduction of jet engines in the late 1940's and early 1950's for civilian and military aircraft gave rise to the consciousness of the need for hearing protection. The high sound pressure levels generated by the jet engines motivated the Military Services to invest in research and development of hearing protectors and basic research on the nature of hearing loss. Most of the helmets, headsets and earplugs available at that time were tested and evaluated for attenuation characteristics. It became necessary, therefore, to establish a standard for the measurement of hearing protector attenuation characteristics. The standard ANSI method was established in the United States in 1957 by which hearing protectors, such as helmets, earplugs and headsets, were tested.

As a result of military investment in research, improved hearing protectors were developed, and also basic research provided predictions about the upper limits of hearing protection that might be developed for use of protecting hearing in hazardous acoustic environments. The results of empirical measurements have generally agreed with the early predicted maximum sound attenuation values obtainable around the human head at various audio frequencies. The modern efficient hearing protectors do not exceed very much the predicted values established by the early research.

From the theoretical predictions of the upper limits of hearing protectors and the empirical data that have been gathered since the 1950's it is known that high frequency attenuation of most hearing protectors is greater than the protection available at low frequencies. For instance, with an efficient hearing protector the real-ear attenuation obtainable at 125 Hz approaches a limit of 24 decibels. Whereas, maximum attenuation possible at 4,000 Hz has been found to be as high as 53 decibels. The maximum attenuation values found among a large sample of hearing protectors are depicted graphically in Figure 1. It must be stressed that the upper limit values are among a large sample of devices. There is no known device that yields the upper limits attenuation values for all test frequencies.

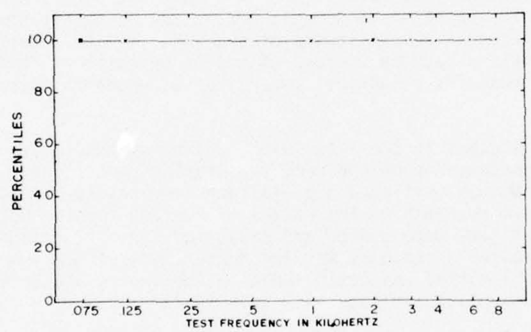
The nonlinear contour in Figure 1 shows that - in general - there is a continuous increase of possible attenuation from 125 Hz up to 4,000 Hz and a slight decline of contour between 4,000 Hz and 8,000 Hz. The irregular area of attenuation within the bounds of the extreme high and low test frequencies of 75 Hz and 8,000 Hz, respectively, and the maximum attenuation values is an indication of why a description of the overall attenuation characteristics of a hearing protector with one averaged value may be ambiguous. For instance, if one refers to the attenuation characteristics of a hearing protector as 25 decibels, ambiguity becomes apparent when one tries to assess the meaning of the overall one-figure evaluation. A hearing protector with 25 dB at low frequencies would be a very efficient attenuator, - whereas a device with 25 decibels attenuation at high frequencies between 3,000 and 8,000 Hz would be a very inefficient hearing protector.

The purpose of this presentation is to present a new method for evaluation of hearing protectors with a single overall value that would be meaningful for the relative evaluation of hearing protectors. The new method measures relative hearing protective characteristics in terms of Attenuation Efficiency Scores (AES). The procedure for computing AES requires the transformation of attenuation decibel values into percentile values. This normalizes the data so that the irregular curve of maximum attenuation values is converted to a straight line shown in Figure 2. It was assumed that the data from a large sample of hearing protectors contained maximum attenuation values that are asymptotic. The attenuation of future hearing protective devices would not be expected to exceed very much the maximum value contours. Therefore percentile values were selected as the basis for an overall measure of relative efficiency.




MAXIMUM REAL-EAR SOUND ATTENUATION OBTAINED WITH A LARGE SAMPLE OF HEARING PROTECTORS

Figure 1




MAXIMUM REAL-EAR SOUND ATTENUATION VALUES IN DECIBELS OBTAINED WITH A LARGE SAMPLE OF HEARING PROTECTORS TRANSFORMED INTO PERCENTILES

Figure 2

Decibel attenuation values at each test frequency were converted into percentiles so that 100 percentile represents the maximum attenuation values and all other decibel values were transformed into percentiles determined by the distribution of attenuation values for each test frequency. Figure 2 depicts the transformation of the irregular curve in Figure 1 into a 100 percentile straight line. The total area under the straight line 100 percentile line was arbitrarily made equal to 100 , or the maximum Attenuation Efficiency Score (AES). All hearing protectors would fall within this area and no device would yield an AES of 100 because there is no known device that yields the maximum attenuation values for all test frequencies.

$$\text{Maximum AES of } 100 = \frac{100 \text{ percentile}}{10} \times \log \frac{\text{upper frequency}}{\text{lower frequency}} \times \text{Constant}$$

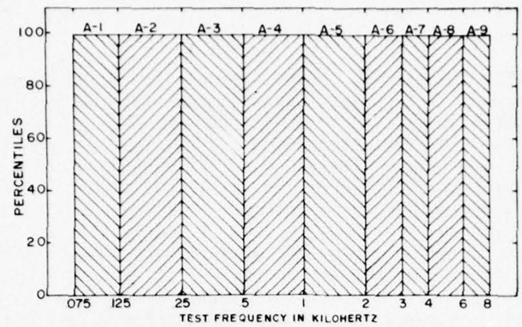
$$\text{AES } (100) = 10 \text{ deciles} \times \log \frac{8000 \text{ Hz}}{75 \text{ Hz}} \times K =$$

$$10 \text{ deciles} \times \log 106.666667 \times K =$$

$$10 \text{ deciles} \times 2.028028724 \times 4.930896631 =$$

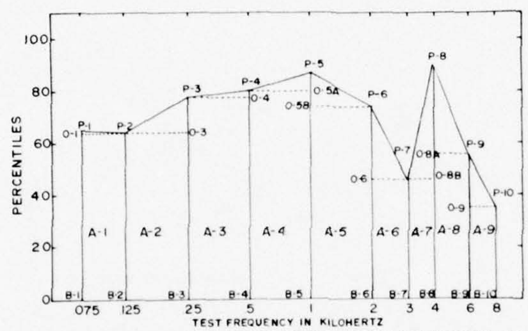
$$10 \text{ deciles} \times 10 = 100$$

The total area then is subdivided into smaller areas as depicted in Figure 3. Each subarea is calculated by an ordinate value in deciles which ranges between 0 and 10 times the difference of the logarithm of the boundary frequencies of the subarea times a constant. For a theoretically perfect hearing protector within the state-of-the-art the area, or AES, would be a total of 100.




AREAS BOUNDED BY TEST FREQUENCIES AND MAXIMA PERCENTILE VALUES USED FOR COMPUTING THE MAXIMUM ATTENUATION EFFICIENCY SCORE (AES 100)

Figure 3




AREAS BOUNDED BY TEST FREQUENCIES AND PERCENTILE VALUES USED FOR COMPUTING THE ATTENUATION EFFICIENCY SCORE (AES) OF A HEARING PROTECTOR

Figure 4

An example of a hearing protector's attenuation characteristics transformed into percentiles and subdivided into areas with the test frequencies as boundaries of each subarea is shown in Figure 4. Each subarea is a column composed of a rectangle the area of which is determined by the boundary frequencies and the percentile values for each of two frequencies. For instance, in Figure 4 the first subarea is formed by the rectangle area B-1 and B-2 at the base and P-2 and O-1 at the top of the rectangle plus the triangle area formed by points P-1, P-2 and O-1. The areas between other adjacent test frequencies are formed in the same manner, and the sum of the subareas yields the overall Attenuation Efficiency Score. The equation for computing the Attenuation Efficiency Score is as follows:

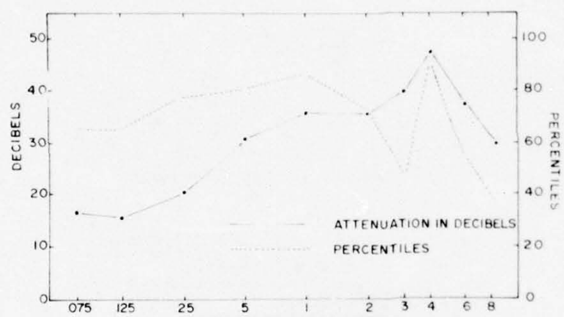
$$AES = \left(\frac{P_{75} + P_{125}}{2 \times 10} \times \log\frac{f_{125}}{f_{75}} \times K\right) + \left(\frac{P_{125} + P_{250}}{2 \times 10} \times \log\frac{f_{250}}{f_{125}} \times K\right) +$$

$$\ldots\ldots\ldots\ldots\ldots\ldots \left(\frac{P_{6000} + P_{8000}}{2 \times 10} \times \log\frac{f_{8000}}{f_{6000}} \times K\right)$$

When $P_{75}$, $P_{125}$, $P_{6k}$, and $P_{8k}$ are percentile values at the indicated test frequencies and $K = 4.930896631$. Table IA in the Appendix contains Percentile Ranks for Mean Real-Ear Attenuation Decibel Values Obtained with 63 Hearing Protective Devices.
Table IIA contains Percentile Values in Decibels for Mean Real-Ear Attenuation Data of 63 Hearing Protective Devices.

It is obvious from the above derivation of the Attenuation Efficiency Score, the AES is the summation of the areas beneath the percentile transform of the decibel attenuation data characteristics of a hearing protector. The normalization of the nonlinear decibel values makes possible unbiased summation of the areas yielded by the various portions of the test spectra and, consequently, yields a single meaningful one value estimate of the overall efficiency of a hearing protector. In Figure 3 it may be observed that the areas between frequencies one octave apart yield equal areas. All other frequency intervals less than an octave have less area. This is determined by the logarithm value of the frequency. With the preferred frequencies used for attenuation testing, the area between 75 Hz and 125 Hz is less than one octave. Also, the areas between the test frequencies 1 kHz and 8 kHz are less than an octave and therefore are smaller than octave band areas. The formula given for the computation may be used for any test frequency that might be chosen - other than the preferred frequencies used in the examples.

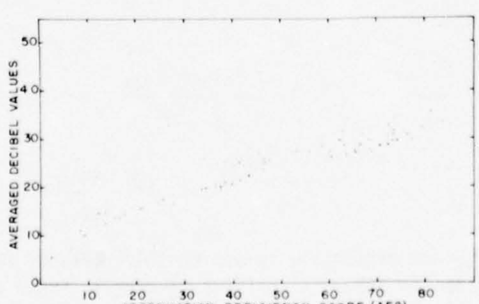
A comparison of the AES with the average decibel values, i.e., the arithmetic mean of attenuation values (referred to as "averaged decibel values") for all test frequencies from 75 Hz to 8 kHz for a given hearing protector shows that among a large sample of more than sixty hearing protective devices the upper decibel arithmetic mean value of the attenuation for all test frequencies was about 35 dB. The lowest mean value was approximately 10 dB. The range of AES values was between 9 and 84. The conversion of decibels to percentiles and the calculation of the AES is preferred over averaging decibel values, because -- first, the ambiguity of the averaging method is eliminated. The high frequency biasing inherent in the averaging method is eliminated. Secondly, a plot of the decibel attenuation values alone does not yield much information about the relative efficiency at each test frequency unless the observer has an extensive knowledge of the limitations of hearing protection at various frequencies. The conversion to percentile values overcomes this disadvantage and immediately conveys to the observer the relative efficiency at a given test frequency. A comparison of the attenuation in decibels and percentile ranks is shown in Figure 5. Note the attenuation in decibels curve at 3,000 Hz. The increasing attenuation characteristics significance can be evaluated only by observing the corresponding percentile value which shows a dip at that point. On the other hand, the next frequency of 4,000 Hz shows a higher attenuation in decibel value which is a significant increase in terms of the state-of-the-art. For the low test frequency range the percentile contour gives a better feeling for the efficiency in these frequencies where the upper limits of attenuation are low-valued.



REAL-EAR SOUND ATTENUATION CHARACTERISTICS OF A DAVID CLARK 10A HEARING PROTECTOR IN DECIBELS AND PERCENTILE RANKS

Figure 5

The scatter diagram of the mean attenuation values in decibels versus AES scores was plotted and a correlation was computed. See Figure 6. The value of the correlation was found to be .97. The mean of the AES values was 49.5, and the mean of the averaged values was 23.9. The standard deviation of the AES values was 23.1, and the standard deviation of the averaged values was 7.0.



SCATTER DIAGRAM OF AVERAGED DECIBEL VALUES VERSUS AES OBTAINED FROM A LARGE SAMPLE OF HEARING PROTECTORS

Figure 6

The objections that have been raised about the use of the AES are that the maximum attenuation obtained in hearing protectors is not fixed and therefore may be variable with time. This is true. However, in recent years we find that very little increase has been obtained over the maximum values that are listed. It is speculated, however, that these values are asymptotic and that there will be very little change in the future -- and the upper limits will not be changed significantly. Even if there are some small changes, the effect on the AES value would be minor. Secondly, it has been appropriately noted that a change of attenuation value at the top end of the scale would not reflect the one-to-one mapping of the magnitude of change. For instance, if one is in the 99 percentile of his peers in some ability, this does not necessarily reflect how much above - in absolute terms. He may be slightly above or he may be superior by a large magnitude. Although the absolute information is not reflected in the AES, there is an advantage of knowing the relative position of a hearing protector in terms of the state-of-the-art. It is believed that the relative evaluation of a hearing protector in terms of the state-of-the-art is appropriate due to the nature of hearing protectors.

As research and empirical testing have demonstrated, hearing protectors have upper limits and therefore cannot be thought of as devices with unlimited attenuation to fit any application that requires extremely high attenuation. So it is important to keep in mind -- in the applications of hearing protectors -- not only the amount of the desired attenuation available, but also how does a particular hearing protector rank among the state-of-the-art devices, and, too - what is the maximum possible attenuation for a given frequency.

The AES is recommended only as extra useful information about the relative evaluation of hearing protectors. In no way is it recommended to replace actual attenuation characteristics in terms of spectral information. It is only with a knowledge of the noise spectra analysis and the real-ear attenuation curves in decibels that one can assure protection against a hazardous acoustic environment. One other disadvantage that has been raised is with reference to the summation of areas between discrete points of attenuation values when the actual contours of attenuation between the test points are not known. For this purpose we assume that the contours between the points are a rough general estimate of the attenuation characteristics of a hearing protector and that the summation of areas is justified on that basis.

In summary, the Attenuation Efficiency Score (AES) has been introduced as a proposed method for expressing the overall attenuation efficiency of hearing protectors. It is a single value estimate of the overall attenuation efficiency that has advantages over the use of averaged decibels. The AES is an unbiased estimate of the relative efficiency of hearing protectors within the state-of-the-art. It is not recommended as a proposed replacement of spectral information that is required for the application of hearing protectors in various types of noise. It may be useful for an overall evaluation of hearing protectors that yield various degrees of attenuation efficiency throughout the audio spectrum. The AES does not have the drawback of making generalizations about noise characteristics as other methods such as the "K" and "S" factors that have recently been introduced. Even with the limitations that have been stated, the Attenuation Efficiency Score is recommended as a useful method for expressing overall attenuation efficiency of hearing protectors.

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# TABLE IA

## PERCENTILE RANK FOR MEAN REAL-EAR ATTENUATION DECIBEL VALUES OBTAINED WITH 63 HEARING PROTECTIVE DEVICES

| Real-Ear Attenuation in Decibels | Frequency in Hertz 75* | 125 | 250 | 500 | 1K | 2K | 3K** | 4K | 6K | 8K |
|---|---|---|---|---|---|---|---|---|---|---|
| - 4 | | | | 1 | | | | | | |
| - 3 | | | | 1 | | | | | | |
| - 2 | | | | 1 | | | | | | |
| - 1 | | 2 | 2 | 2 | | | | | | |
| 0 | | 3 | 3 | 2 | | | | | | |
| 1 | 1 | 5 | 6 | 2 | 1 | | | | | |
| 2 | 2 | 8 | 10 | 3 | 1 | | | | | |
| 3 | 4 | 12 | 13 | 6 | 2 | 1 | | | | |
| 4 | 7 | 16 | 17 | 6 | 2 | 1 | | | | |
| 5 | 11 | 18 | 21 | 8 | 2 | 1 | | | | |
| 6 | 17 | 21 | 23 | 10 | 3 | 2 | | | | |
| 7 | 22 | 25 | 24 | 13 | 4 | 2 | | | | |
| 8 | 25 | 28 | 25 | 17 | 6 | 2 | | | | |
| 9 | 28 | 33 | 30 | 18 | 7 | 3 | | | 2 | 1 |
| 10 | 32 | 37 | 34 | 20 | 9 | 3 | | | 2 | 1 |
| 11 | 35 | 43 | 37 | 21 | 10 | 3 | | | 2 | 1 |
| 12 | 38 | 47 | 40 | 23 | 13 | 3 | | | 3 | 2 |
| 13 | 45 | 50 | 42 | 25 | 15 | 4 | | | 3 | 2 |
| 14 | 52 | 55 | 45 | 27 | 16 | 4 | | 1 | 3 | 2 |
| 15 | 58 | 59 | 51 | 29 | 18 | 4 | | 1 | 3 | 3 |
| 16 | 66 | 64 | 56 | 30 | 22 | 6 | | 1 | 4 | 3 |
| 17 | 72 | 74 | 61 | 33 | 25 | 8 | | 2 | 4 | 3 |
| 18 | 79 | 83 | 67 | 37 | 26 | 9 | | 2 | 4 | 4 |
| 19 | 84 | 88 | 74 | 38 | 29 | 11 | | 2 | 4 | 4 |
| 20 | 89 | 92 | 78 | 41 | 31 | 14 | | 3 | 5 | 5 |
| 21 | 93 | 94 | 81 | 45 | 33 | 16 | 2 | 3 | 5 | 6 |
| 22 | 94 | 95 | 84 | 46 | 37 | 18 | 2 | 5 | 5 | 6 |
| 23 | 96 | 98 | 89 | 48 | 40 | 22 | 3 | 6 | 5 | 10 |
| 24 | 98 | 100 | 92 | 52 | 41 | 25 | 3 | 6 | 6 | 13 |
| 25 | 100 | | 94 | 57 | 44 | 26 | 4 | 7 | 9 | 16 |
| 26 | | | 96 | 62 | 48 | 30 | 4 | 7 | 11 | 19 |
| 27 | | | 97 | 64 | 52 | 34 | 5 | 7 | 13 | 22 |
| 28 | | | 98 | 66 | 56 | 37 | 5 | 8 | 19 | 26 |
| 29 | | | 100 | 67 | 60 | 40 | 6 | 11 | 28 | 31 |
| 30 | | | | 73 | 64 | 44 | 7 | 15 | 26 | 37 |
| 31 | | | | 80 | 68 | 48 | 9 | 19 | 28 | 43 |
| 32 | | | | 84 | 73 | 52 | 11 | 23 | 30 | 47 |
| 33 | | | | 87 | 75 | 58 | 15 | 27 | 31 | 53 |
| 34 | | | | 90 | 78 | 65 | 20 | 31 | 35 | 60 |
| 35 | | | | 92 | 81 | 75 | 26 | 37 | 39 | 66 |
| 36 | | | | 94 | 87 | 83 | 30 | 43 | 46 | 73 |
| 37 | | | | 95 | 90 | 88 | 35 | 47 | 56 | 79 |
| 38 | | | | 96 | 92 | 93 | 39 | 53 | 59 | 85 |
| 39 | | | | 97 | 94 | 100 | 46 | 59 | 65 | 90 |
| 40 | | | | 100 | 95 | | 54 | 61 | 70 | 92 |
| 41 | | | | | 97 | | 61 | 67 | 72 | 94 |
| 42 | | | | | 100 | | 70 | 75 | 78 | 95 |
| 43 | | | | | | | 78 | 79 | 81 | 96 |
| 44 | | | | | | | 87 | 82 | 83 | 98 |
| 45 | | | | | | | 90 | 84 | 85 | 98 |
| 46 | | | | | | | 92 | 87 | 87 | 100 |
| 47 | | | | | | | 94 | 90 | 89 | |
| 48 | | | | | | | 96 | 93 | 93 | |
| 49 | | | | | | | 97 | 94 | 94 | |
| 50 | | | | | | | 100 | 95 | 95 | |
| 51 | | | | | | | | 98 | 97 | |
| 52 | | | | | | | | 98 | 100 | |
| 53 | | | | | | | | 100 | | |

* Comparisons Obtained with 63 Hearing Protective Devices
**Comparisons Obtained with 27 Hearing Protective Devices

TABLE IIA

Percentile Values in Decibels for Mean Real-Ear Attenuation Data of 63 Hearing Protective Devices

| Percentile | 75 Hz* | 125 Hz | 250 Hz | 500 Hz | 1 KHz | 2 KHz | 3 KHz** | 4 KHz | 6 KHz** | 8 KHz |
|---|---|---|---|---|---|---|---|---|---|---|
| $P_{10}$ | 4.9 | 2.6 | 2.1 | 5.8 | 10.9 | 18.6 | 32.2 | 28.6 | 25.9 | 23.1 |
| $P_{20}$ | 6.6 | 5.7 | 4.8 | 10.1 | 15.4 | 22.4 | 34.4 | 31.3 | 28.2 | 26.3 |
| $P_{30}$ | 9.6 | 8.5 | 9.0 | 15.9 | 19.4 | 26.0 | 36.0 | 33.8 | 32.6 | 28.8 |
| $P_{40}$ | 12.3 | 10.6 | 12.1 | 19.8 | 23.7 | 28.9 | 38.3 | 35.3 | 35.3 | 30.3 |
| $P_{50}$ | 13.7 | 13.0 | 14.9 | 23.3 | 26.6 | 31.3 | 39.3 | 37.6 | 36.3 | 32.6 |
| $P_{60}$ | 15.2 | 15.4 | 16.8 | 25.4 | 28.9 | 33.3 | 40.9 | 39.4 | 38.6 | 33.9 |
| $P_{70}$ | 16.7 | 16.6 | 18.3 | 29.7 | 31.3 | 34.6 | 41.9 | 41.3 | 40.4 | 34.9 |
| $P_{80}$ | 18.2 | 17.6 | 20.7 | 31.0 | 34.7 | 35.4 | 43.3 | 43.6 | 43.1 | 37.2 |
| $P_{90}$ | 20.2 | 19.4 | 23.8 | 34.6 | 37.4 | 37.4 | 45.8 | 46.8 | 48.1 | 39.2 |
| $P_{100}$ | 25.0 | 24.0 | 29.0 | 40.0 | 42.0 | 39.0 | 50.0 | 53.0 | 52.0 | 46.0 |

* Computed from data of 61 hearing protective devices.

**Computed from data of 27 hearing protective devices.

## DISCUSSION

**Dr H.Von Gierke, USA**

The AES might have some merit for expressing overall attenuation efficiency in developing ear protectors, although I feel it is unfair to use the same maximum attenuation curve for all types of protectors. We know very well that the theoretical limits for maximum protection are different for the different types i.e. earplugs, muffs and helmets. However, the AES cannot replace the various methods of averaging decibels, which have been developed to give a practical answer to the question: how much is the A-weighted sound level at the tympanic membrane reduced by the ear protector compared to the free-field environmental noise level. The AEA is not able to answer this practical question. For this reason it appears to me that the averaged attenuations as being used by the USAF and the US OSHA are the practical average attenuation measures most useful for the evaluation of ear protector effectiveness.

# NOISE LEVELS AND THEIR MEASUREMENTS AND INTERPRETATION IN THE VICINITY OF MILITARY AIRFIELDS

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## INTRODUCTION

In order to assess the increasing problem of noise the UK Government set up a committee in 1960 to examine the nature, sources and effects of the problem of noise and to advise what further measures can be taken to mitigate it. For the purpose of this task the committee adopted the definition of noise as "sound which is undesired by the recipient" (1) This definition emphasised the cardinal principle that noise in this context is subjective, and therefore appropriate when considering noise which gives rise to complaints. It is recognised that these complaints are due to the general effects of such noise and include:-

a. Interference with communication, and

b. disturbance of work, recreation or sleep.

In order to assess these main effects many studies and surveys were carried out in the UK. From these studies and subsequent work indices for nuisance noise from road traffic, aircraft and industrial premises have been formulated. These indices are primarily related to the civilian environment and based on them statutory instruments have been framed. The noise source with which we are concerned is that from aircraft, in particular the noise in the vicinity of airfields. In view of the legislation in existence to provide recompense for the population affected by noise levels in excess of the criteria laid down for civil airfields the Royal Air Force was required to recommend comparable criteria for noise in the vicinity of military airfields.

## NOISE INDICES USED IN THE UNITED KINGDOM

At the present the three types of noise source identified for the purpose of planning control and legislation are:-

a. Road traffic

b. Aircraft noise

c. Industrial premises

The different characteristics of these noise sources have resulted in a different index for each.

### Road Traffic

Investigations of the subjective assessment of motor vehicle noise indicated that dissatisfaction towards traffic noise was dependent on the level and variability of the noise. In a subjective experiment designed to establish a relationship between the subjective rating of noise emitted by motor vehicles, and objective measurements made with a sound level meter employing A-weighting Mills and Robinson (2) showed that a satisfactory correlation is obtained between the subjective and objective measurements in the case of private cars and commercial vehicles. Based on all the available data a measure called the Traffic noise Index (TNI) was formulated. This index was intended to correlate with average dissatisfaction and combined a measure of background level with one of the difference between traffic noise peaks and background noise (3). The measurement of TNI proved to be difficult because of the variability of background noise from sources other than road traffic; prediction would also have been difficult on the available data. Because of this the $L_{10}$ (18 hour) value has been adopted for the present for use in noise legislation (4).

The $L_{10}$ scale gives a measure of the level of noise exceeded for 10 per cent of the time. The $L_{10}$ (18 hour) value is the arithmetic mean of the $L_{10}$ values derived from 18 sample periods, one for each of the hours between 0600 and 2400 hours, in a normal working day. The sample periods should not be less in duration than 5 minutes and could be much more. The $L_{10}$ (18 hour) index is used in controlling housing development. Residential development is considered by the UK Noise Advisory Council as having a limit of acceptability of 70 dB(A) in the $L_{10}$ (18 hour) scale. In addition, building specifications must not produce an internal $L_{10}$ (18 hour) with windows closed, of greater than 50 dB(A) on this scale; it has been suggested that a good standard would be 40 dB(A) (5).

### Aircraft Noise

The problem of aircraft noise came to the forefront only after the second World War. Though there were large numbers of aircraft during the war and few parts of Great Britain were unaffected by their noise, this was regarded as a sign of strength. Post war expansion of civil aviation was concentrated on a small number of airfields. Complaints about aircraft noise were received and began to increase. The transition from piston engine to turbo-propeller aircraft brought a further increase, and the advent of the large turbo-jet aircraft made noise in the vicinity of civil airports a major problem.

Ir was necessary to obtain subjective assessments of aircraft nose, relate these to objective measurements and attempt to formulate noise measures which would be acceptable to the majority of those exposed. Robinson (1) carried out an experiment at the SBAC Show at Farnborough in 1961 where sixty subjects made judgements of the sounds of aircraft flying overhead. Two rating scales were used for outdoor judgements using the criteria of "noisiness" and intrusiveness. Noise levels were expressed in dB(A) and PNdB. There was a subjective relationship between the scales of intrusiveness and noisiness which correlated with objective measurement of sound levels; this is shown diagrammatically in Fig 1.

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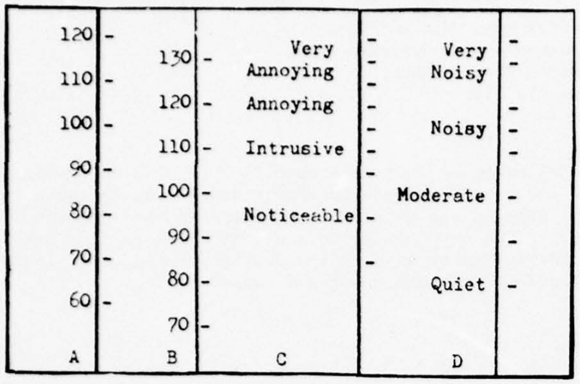
Fig. 1




Line A = Sound Level dB(A)

B = Perceived Noise Level PNdB

C== Subjective Intrusiveness

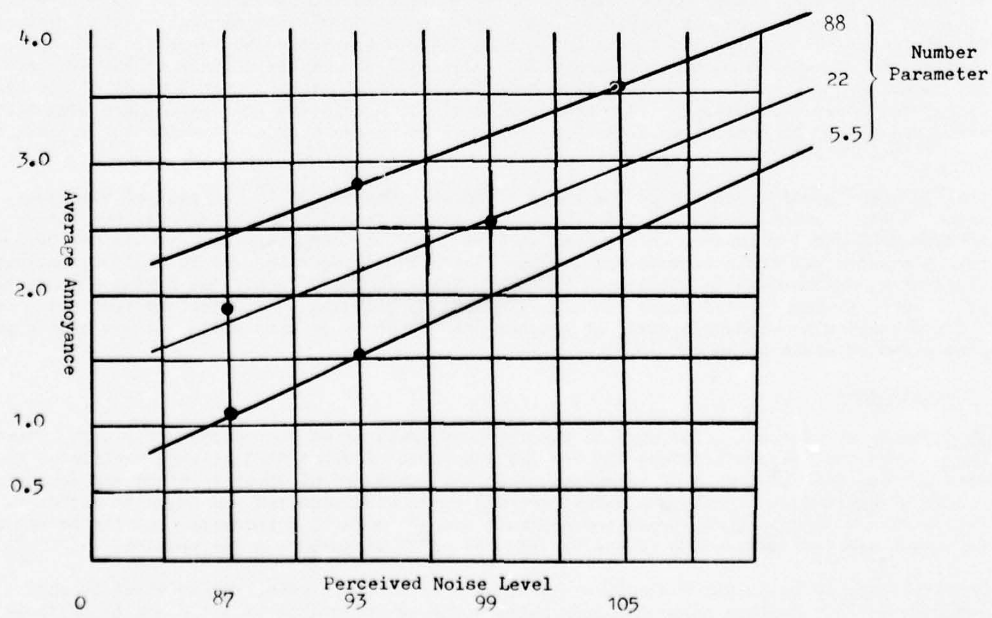
D = Subjective Noisiness

RELATIONSHIP BETWEEN THE OBJECTIVE SCALES OF SOUND LEVEL A AND PERCEIVED NOISE LEVEL (PNdB), AND THE CATEGORY SCALES OF INTRUSIVENESS AND NOISINESS. (Committee on the Problem of Noise 1963).

A comparison of the perceived noise levels (PNdB) and sound levels (dB(A)) for numerous aircraft noises showed that the two measures may be regarded as having a constant difference of about 13.

Another source of valuable data was a social survey in the vicinity of London (Heathrow) airport. This survey covered all the residential districts within 10 miles of the airport (1). From the physical measurements carried out, 14 different variables could be isolated as comprising the noise climate. There were also 58 socio-psychological variables which could be identified from answers to questionnaires. Following extensive analysis by computer it was found that all the significant correlations with physical variables could be reduced to two, namely those with average peak noise level of the aircraft and with the number heard per day. In essence it appeared that annoyance was a function of the average peak noise level of the aircraft and the number of flights per day. It was possible therefore to attempt an equivalence between a change in noise level and number. One way of doing this was to plot the average annoyance against the noise level. To estimate the equivalence, three lines were drawn so that they were parallel, equidistant and fitted the points well. It was possible to achieve a good fit taking the values for the number parameter as 5.5, 22, and 88; they form a geometrical series of ratio 4. Fig. 2 shows this relationship.

Fig. 2




RELATION BETWEEN AVERAGE ANNOYANCE AND PERCEIVED NOISE LEVELS (Committee on the Problem of Noise 1963).

A similar result can be obtained using the method of least squares giving weight to the point in each cell proportional to the number of observations. From Fig. 2 it can be seen that the annoyance rating seems to vary almost linearly with the total noise exposure figure and that zero annoyance is indicated at about 80. This figure was subtracted from the total noise exposure figures in PNdB, the resultant value is described as the Noise and Number Index (NNI). The Noise and Number Index therefore uses the average values of the maximum perceived noise level together with the number of aircraft heard in a specified period and can be derived from the following formula:-

$$NNI = \overline{L}_{PN\ max} + 15 \log_{10} N - 80$$

Where $\overline{L}_{PN\ max}$ = average (taken logarithmically) of the maximum perceived levels attained during passage of successive aircraft and,

N = the number of aircraft heard in a defined daytime period.

At present it is advised by the Department of Environment that building permission should be refused at 60 NNI and above, and that no major developments should be allowed in areas of 40-60 NNI. At London (Heathrow) Airport sound proofing grants are allowed within the 55 NNI contour. It is this value of 55 NNI which required an equivalence in terms of military airfields.

UK Industrial Noise

Control on noise from industrial premises and other fixed installations is on the basis of Corrected Noise Level (CNL) rating method involving the index described in British Standard BS 4142 (6). In this system, the level of noise emitted from industrial premises, in dB(A) is corrected for tonal, impulsive, intermittent and duration aspects. Should the resultant value of CNL exceed 75 dB(A) by day or 65 dB(A) by night, new development would scarcely ever be justified for residential or other noise sensitive uses.

In addition to the above indices, it must be noted that prolonged exposure to noise from aircraft at close proximity cannot be dismissed as having no possible effect on hearing. Thus it is relevant to take note that the "Code of Practice for Reducing the Exposure of Employed Persons to Noise", issued by the Department of Employment (7), recommends that occupational exposure to Equivalent Continuous Sound Level (Leq) of noise more than 90 dB(A) for a nominal 8 hour day requires the use of ear protection. However, this is to be regarded as a maximum acceptable and not as a desirable level. The use of Leq in this context is an essential concept and this index is now widely accepted at national and international level for a variety of purposes.

UK Noise Induced Hearing Loss: Noise Imission Level

The British Standards Institution has produced a new standard method for estimating the risk of hearing handicap due to noise exposure (8). The standard is in effect the logical outcome of the earlier ISO R 1999 (ISO 1971), which was influenced by British data from the Medical Research Council - National Physical Laboratory survey (9). These data were based on the acceptance of the principle that total energy reaching the ear determines the extent and frequency distribution of noise induced hearing change. The standard provides an explicit procedure which, given the equivalent sound level, the duration of exposure and the age of the population, will yield a value designated the "handicap percentage". For purposes of this procedure the equivalent continuous sound level is defined as a notional continuous sound level in dB(A) which if present for a specified duration (e.g. 8 hours) could cause the same A-weighted sound energy to be received as that due to an actual sound occurring in a specified duration, and Noise Immission Level (NIL) is defined as the A-weighted noise immission, expressed in decibels relative to a specified duration. Noise immission is taken as the index of the total energy incident on the ear over a specified duration.

## SUITABILITY OF EXISTING INDICES FOR MILITARY AIRFIELDS

The $L_{10}$ (18 hour) index used for road traffic was primarily intended for busy main roads carrying freely flowing traffic. It had the disadvantage that it did not take account of background noise in that given a quiet background the passage of a given flow of vehicles was more disturbing (in an incremental sense) than that of the same traffic heard against a noisy background.

The Noise and Number Index (NNI) was developed from surveys carried out around London (Heathrow). Its suitability for other airports can be questioned. Also NNI does not take into direct account general background noise except to stipulate a lower level of 80 PNdB in relation to the number of aircraft counted as "heard". Another criticism is that ground running of aircraft engines is excluded in the derivation of NNI. Further, NNI cannot be stated to reflect the true response of the majority of those exposed when high noise levels are produced by a few aircraft performing, for example, training profiles.

Finally, the Corrected Noise Level (CNL) for industrial purposes was derived for prediction of complaints (11), and surveys have shown that the relationship between the volume of complaints and the extent of annoyance is extremely complex; the former does not necessarily reflect the latter. CNL is a useful tool for planning purposes.

## MILITARY AIRFIELD NOISE

Against the background of the foregoing concepts, recommendations and current planning restrictions, together with possible future legislation the need is for a rationalised, and possibly single index system for quantifying the various types of disturbance: Robinson's (12) (13) consideration of this problem produced the Noise Pollution Level ($L_{NP}$). The index $L_{NP}$ is in an early stage of development. It includes the effects of background noise and may well in future supplant other measures as a unified scale for quantifying different varieties of noise disturbance.

However, it was felt to be more difficult to derive than was desirable for the present purpose. In view of this the Royal Air Force Environmental Noise Advisory Committee agreed to accept the proposal that the A-weighted sound level be used for the measurement of sound in the vicinity of military airfields and at the present time the specification of noise levels around Military Airfields be based on equivalent continuous sound level (Leq).

The choice of a value of Leq may be approached through an examination of the equivalent values of the various indices noted above, which are in current use for planning purposes. Fuller and Robinson (14) and Berry (15) have examined the various aspects of these indices. Berry's study is of immediate relevance to the present problem, since he derives equivalent values of the appropriate indices for road traffic, aircraft and industrial noise, and compares his findings with the officially recommended values. The methods are of some complexity, but in essence $L_{10}$ is compared with NNI (making various assumptions on air traffic patterns) through the intermediary of Leq or $L_{NP}$. The equivalences derived through $L_{NP}$ are as follows:-

| $L_{10}$ | Leq | NNI | $L_{NP}$ | CNL |
|---|---|---|---|---|
| 70 dB(A) | 67 dB(A) | 38 | 76 | 72 |

These are outdoor values and standard deviations are omitted.

Incompatibilities still exist in the duration and times associated with these indices which are yet to be resolved. Nevertheless, it is clear that the Department of the Environment Planning and Noise Circular recommendations (5) agree with the theoretical derivations, and the recommended values indicate equal degrees of acceptability at those levels.

In assigning a value of Leq for the present purpose the civil airfield value of 55 NNI may be taken as the guide. It is necessary to derive an Leq value equivalent to this. Berry's (15) estimate of equivalences between Leq and NNI described above indicates that 67 dB(A) corresponds to 38 NNI. The propriety of simply adding equal values in dB to both may be argued, but as a final step no immediate alternative is open. Thus 55 NNI should imply an Leq of 84 dB(A). To put this comparison into perspective the durations associated with the values must be considered. The NNI value is a daytime logarithmic average over the hours 0600-1800 in summer, whereas 67 dB(A) is derived from $L_{10}$ (18 hours) from 0600-2400 hours. If the Leq of 84 dB(A) is accepted for 18 hours, the 8 hour equivalent would be 87.5 dB(A). This result exceeds the occupational exposure maximum permitted by RAF Defence Council Instructions (16), and was therefore considered unacceptable.

However, if an alternative solution is sought, Berry (15), using Leq as the means of conversion between $L_{10}$ and NNI, derived a value of 49 NNI as equivalent to an $L_{10}$ of 70 dB(A) or an Leq of 67 dB(A). Using this equivalence, the Leq for 55 NNI would be 73 dB(A). If this value is associated with the same duration as above, i.e. 18 hours, it would imply an 8 hour value of 76.5 dB(A), or a 24 hour value of 71.5 dB(A). A compromise as the mean of the 8 hour values obtained by the two methods would place the 8 hour Leq at 82 dB(A). It was felt that a more appropriate figure would be to round it off to 80 dB(A) thus making the 24 hour value 75 dB(A). This value has been accepted as the equivalence to 55 NNI in the Royal Air Force.

This criterion has now been in existence for nearly 2 years and the indications are that it reflects the true reactions of the majority of those exposed to noise in the vicinity of military airfields. It is emphasised however, that in view of the apparently arbitrary nature of the final computation the criterion will be continuously assessed under actual operating conditions and revision to a lower value is not excluded.

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## DISCUSSION

**Dr Henning E.Von Gierke**

I have not received a copy of the question. Dr Von Gierke made a comment on the application of equivalent continuous sound level (Leq) in the United States. This was acknowledged. The question in regard to my paper was whether any weighting/allowance was made for night-time disturbance in arriving at the criterion Leq(24)75dB(A) for noise in the vicinity of military airfields.

**Author's reply**

An allowance or weighting for night-time noise was considered in the derivation of the Leq(24)75dB(A). In considering a 24 hour Leq, it is customary to add a weighting say 10 to the night-time Leq and calculate the 24 hour Leq from these values according to the formula.

$$\text{Leq}(24) = \text{Ldn} = 10 \text{ Log}_{10} \frac{dh \times 10^{Ld/10} + nh \times 10^{\frac{Ln + 10}{10}}}{24}$$

Where dh = daytime hours
dn = night-time hours
Ld = daytime Leq
Ln = night-time Leq
Ldn = calculated Leq for 24 hours

Four our purpose, having arrived at a 24 hour Leq of 75dB(A) by translation of the existing indices, it was felt that the various combinations which would make the Leq(24)75dB(A) be examined and then stipulate a night-time Leq to still be within limits of the 75dB(A) as the 24 hour Leq. The following steps will explain our approach.

1. Leq(24)75dB(A) may be distributed as follows:

75dB(A) for 24 hours
76dB(A) for 18 hours and 0 for 6 hours
78dB(A) for 12 hours and 0 for 12 hours
80dB(A) for 8 hours and 0 for 16 hours

2. If we consider an 18 hour value similar to the $L_{10}$ 18 hour value for road traffic, the value of 76dB(A) could be taken as the daytime Leq(18) and various Leq values for night-time Leq(6) were chosen and their influence on the Leq 24 hour calculated as follows:

$$\text{Leq}(24) = 10 \text{ Log}_{10} \frac{18 \times 10^{76/10} + 6 \times 10^{\text{Ln}/10}}{24}$$

(a) Night-time weighting of 10. Ln = 66dB(A)

$$\text{Leq}(24) = 10 \text{ Log}_{10} \frac{18 \times 10^{76/10} + 6 \times 10^{66/10}}{24}$$

$$= 74.89 \text{ dB(A)}$$

(b) Night-time weighting of 20. Ln = 56dB(A)

$$\text{Leq}(24) = 10 \text{ Log}_{10} \frac{18 \times 10^{76/10} + 6 \times 10^{56/10}}{24}$$

$$= 74.87$$

(c) Night-time weighting of 31. Ln = 45dB(A)

$$\text{Leq}(24) = 10 \text{ Log}_{10} \frac{18 \times 10^{76/10} + 6 \times 10^{45/10}}{24}$$

$$= 74.75$$

(d) Night-time weighting of 36. Ln = 40dB(A)

$$\text{Lwq}(24) = 10 \text{ Log}_{10} \frac{18 \times 10^{76/10} + 6 \times 10^{40/10}}{24}$$

$$= 74.75$$

The deviation of Leq(24)75 with a weighting range between 10 and 36 is not significant and we are confident that the present type of operations will enable us to contain the night-time disturbance within these values.

# US Air Force Environmental And Occupational Health Program

by

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Aerospace Medicine Division
Air Force Surgeon General
Washington, DC 20314

SUMMARY

The United States Air Force has the primary mission to maintain its operational capability and a secondary, but by no means a lesser concern to protect its employees and local citizens. The greater awareness of the inter-relationship between man and his environs has caused the Air Force and its surrounding communities to integrate their efforts to cope with the problems in today's society. The major concepts considered today are air and water pollution, noise, control, national environmental policy act, and occupational safety and health. In addition, there are the obvious specific industrial and environmental health problems associated with aircraft servicing and maintenance, fuel spillage, wash rack effluent, industrial wastes, drinking water, and electromagnetic energy.

The overall environmental and occupational health problems and how the United States Air Force is coping with them is addressed. The numerous laws and the impact on the daily activities of the Air Force are discussed. Also, it covers the manpower and organizational structures the Air Force has created and proposes to create in response to new legislation and policies.

## INTRODUCTION

The impact of current occupational and environmental legislations and their implementing directives is certainly having far-reaching effects on the Air Force. However, protection of the work place and the environmental and national defense are not incompatible. At the Air Force Academy, there is a pillar outside the dining hall with an inscription "Man's flight through life is substained by the power of his knowledge". Sustenance today means not only conquering space but also sustaining the life of our planet and its people. The Air Force is capable of accomplishing its portion of both of these objectives. We can not accomplish the second objective without the assistance of our neighbors. Only if we can integrate our activities with our neighbors through the world can we cope with the problems in today's society.

We are working hard to insure that the Air Force is fitting occupational safety and health and environmental quality into our day-to-day business. This is a formidable task considering the Air Force carries out its job of national defense from almost 200 major air bases and literally thousands of lesser installations scattered on all parts of the globe.

In my discussion here today, I will address the overall environmental and occupational health programs as implemented by laws and how they have impacted the daily activities of the Air Force. There will be specific emphasis on the Medical Service responsibilities for establishing criteria and standards to insure compliance with applicable laws and for developing an adequate monitoring program. The other activities in the Air Force responsible for procuring, building and operating the facilities and equipment to be in compliance with the environmental and occupational safety and health laws and regulations are also discussed. Let's first look at the program that affect the atmosphere.

## ATMOSPHERIC

Congress had not been satisfied with progress in cleaning up the air since the first legislations had been passed in 1955. As a result, they enacted the 1970 amendments to the Clean Air Act. These amendments have had the biggest impact and increased the air pollution program efforts. They increased the Air Force efforts which started as a result of the 1963 and 1967 amendments.

As a result of the 1970 amendment, national air quality standards were fixed for six major air pollutants - carbon monoxide, particulates, sulfur oxides, hydrocarbons, nitrogen oxides, and photochemical oxidants. Also, major sources of air pollution had to prepare and follow compliance schedules designed to clean up particular pollution problems.

To assist in determining the Air Force's compliance, the Environmental Health Laboratory at McClellan AFB, California, developed air pollution sampling teams which have been certified by the Environmental Protection Agency. In part, their efforts have identified the need from FY 1968 to FY 1976 for the Air Force to expend over $52,000,000 to control air pollution from its fixed facilities worldwide. In FY 1977 and 1978, it is estimated the Air Force will spend an additional $42,000,000.

In June 1975, the Secretary of the Air Force established aircraft engine emission goals for carbon monoxide, hydrocarbon, oxides of nitrogen and smoke. This was done recognizing the existence of Environmental Protection Agency standards for commercial aircraft and the essentiality that emission controls applied to Air Force engines not infringe upon flight safety and combat effectiveness. The goals were established for turbonfan, turbojet and turboprop engines beginning development after June 1975.

NOISE

Since the early 1950s, there have been a number of measures recommended to try to reduce or control the increased noise levels from industrial plants, ground traffic and aircraft. However, it took the Noise Control Act of 1972 and the Federal Aviation Regulation Part 36 as amended to tie together differing viewpoints and lack of agreement on common goals. We have four areas of particular interest concerning noise abatement or control. These are (1) ground runup, (2) hearing conservation, (3) land use planning, and (4) equipment generating levels.

To address the ground runup problem the Air Force has spent $46 million for the period FY 1969 through FY 76 to procure and install sound suppressors. The objectives of the program are:

(1) Protect maintenance personnel performing test and trim operations from sound intensities of over 135 decibels.

(2) Eliminate the hearing damage risk for personnel without ear protection working up to eight hours a day at 250 feet or more from the power check pad or jet engine test stand.

(3) Provide a communication environment inside a frame building with windows and doors partly open, equivalent to that normally experienced in shop areas with moderately noisy machinery or in hangars used for routine aircraft maintenance when operated at 500 feet from such a building.

(4) Provide sufficient suppression so that essentially no complaints would be expected from a residential community 2500 feet from the power check pad or jet engine test stand while making up to five single engine runs per day of more than five minutes duration between the hours of 0700 and 2200.

(5) Allow continuous around-the-clock operations one mile from a residential community.

As you can see, this program addresses both the hearing conservation of our personnel and community relations. The Air Force initiated its comprehensive hearing conservation program in 1956. We have a program of educating personnel about hearing damage due to noise, insisting on the use of ear protective devices and conducting about 320,000 hearing tests each year to monitor the health of personnel being exposed.

Another aspect of noise control is land use planning. As our nation becomes more populous and suburban development mushrooms, our air fields are being subjected to an ever tightening squeeze. In order to protect our air fields, the Department of Defense has initiated the Air Installation Compatible Use Zone (AICUZ) program to identify and accomplish compatibility with its neighbors. The Air Force program should; (1) minimize the impact on all persons and activities, (2) describe and evaluate the noise and accident potential aspects, (3) provide planning information to civilian and governmental groups who are concerned with planning and the environment, and (4) engage in a cooperative planning process.

An important aspect of land use planning is in the modification of operational procedures. Flight operations of military aircraft are unique. However, the Air Force plans its flight paths and mission profiles to minimize when possible the effect of noise on the populace.

The last area involves designing and procuring equipment that is less noisy. An example of the Air Force efforts is the requirement to procure and develop transport aircraft designed to comply with Civil Airworthiness Standards. This and other aircraft noise control and abatement policies are the subject of the Secretary of the Air Force, 13 March 1974, memorandum. This shows the Air Force desire to maintain leadership in protecting the environment and promoting an environmental policy consistent with our national security mission.

ENVIRONMENTAL STATEMENTS

It is almost six years since the National Environmental Policy Act (NEPA) became law. Although the law dealt with an issue of great public interest, it caused little fanfare and attracted little attention from Congress and from Federal agencies. They believed it to be another advisory environmental policy with few teeth.

Sequently, we found out how wrong this evaluation was. This law has provoked lawsuits, stopped some Fedral actions completely, and delayed others. It has required Federal agencies to be more responsive to environmental considerations and values, which had been too frequently neglected in government decision-making. It has demanded a major new way of thinking and acting by agencies of the Federal Government. Specifically, it required the Air Force to bring environmental concerns into the beginning of the decision-making process. Careful documentation of the decision shows our concern and puts us in good shape to face any court action. Then the real goal of NEPA, to ensure that consideration of the environment is made without pre-judgement and with adequate public participation is met.

Since the law was passed, the Air Force has published 27 environmental statements. They have ranged from the development and procurement of the B-1 and F-15 aircrafts to the F-15 Beddown at Luke and Langley AFBs. Other examples of environmental statments are on the location of over-the-horizon-radar in Maine and Blair Lakes Range in Alaska. The average cost of these 27 statements is about $120,000 each and about a year in preparation and filing.

To aid Air Force installations with the preparation of environmental statements, the Civil Engineering Center, Tyndall AFB, Florida, was appointed the Air Force manager of environmental assessment capabilities. They have also been involved with socio-economic analyses and land use-studies. The Medical Service Environmental Health Laboratories at McClellan AFB, California, and Kelly AFB, Texas, have had an important role in assisting Air Force installations in considering the natural environment in the decision-making process.

BASE SUPPORT

In addition at our installations, we find a vast spectrum of activites, products of modern technology, and processes which impact on the environment -- sanitary and industrial liquid waste, solid waste, electromagnetic energy, emissions into the air from petroleum storage and dispensing, and impacts on land use and natural resources conservation.

Beginning in fiscal year 1965 and carrying through fiscal year 1976, the Air Force will have spent almost $130 million for new facilities to combat water pollution at its installations. This is in addition to $160 million in abatement facilities that were already in place in 1965. The work has involved upgrading and expansion of plant facilities for treating sanitary and industrial liquid wastes and related improvement of collection systems.

We have been working toward the reduction of waste material. Actions include recycling and resource recovery programs at 44% of our bases, use of plant effluents for irrigation, the pulping of paper, as well as a host of controls to prevent petroleum spillage and to better segregate used oils to enhance their marketability. We can no longer "toss things over the fence" and be rid of them. We must consider every process and its wastes. We can't really throw anything away. We just change the location of the problem. Our objective is no waste products, only by-products which are utilized in a recycling process.

The latest action involves the Safe Drinking Water Act which was passed [illegible] December 1974. The Environmental Protection Agency published their interim primary standards in December 1975 and they become effective in June 1977. Based on our review of the standards, we don't anticipate any great difficulty providing water that is as good or better than the standards. However, the Environmental Protection Agency is still attempting to determine whether there is an adequate basis for establishing maximum contaminant levels for specific organics or groups of organics. They are embarking on an intensive research program to answer the following question:

What are the sources, ambient levels of human health effects, treatment technology and control costs associated with commonly occurring organic compounds in drinking water. When this question is answered and the standards published, there could be a requirement for additional analyses and modification of our water supplies. This could also require DoD research and development to comply with this requirement.

OCCUPATIONAL SAFETY AND HEALTH

The Air Force has conducted an effective Occupational Safety and Health Program for years. The program has been elevated in importance since the passage of the Occupational Safety and Health Act in 1970 and publication of the latest Executive Order 11807 in September 1974. It has been this Executive Order which has had the impact on the Air Force. It furnished guidance to federal agencies on the implementation of effective occupational safety and health programs, provided for the evaluation of federal agency programs by the Department of Labor and for the transmittal of these evaluations to the President. It also authorized the Department of Labor to issue guidelines to help federal agencies establish and operate their programs. Title 29, Code of Federal Regulations, Part 1960 (20 CFR 1960) was published 9 October 1974 as the guidelines to federal agencies for operating and establishing their safety and occupational health program.

The Occupational Safety and Health Act and the Department of Labor guidelines 29 CFR 1960 has impacted the Air Staff in Washington, D.C. In the Surgeon General Office, we have spent considerable effort in reviewing almost 100 health standards proposed by the Department of Labor and National Institute for Occupational Safety and Health. In addition we are presently in the process of preparing Air Force Occupational Safety and Health (AFOSH) Standards that are consistent with 29 CFR 1960 requirements.

The Air Force Inspection and Safety Center, Norton AFB, California, is preparing the AFOSH Standards consistent with Occupational Safety and Health Act Safety Standards. The Surgeon General is preparing AFOSH health standards. Before this program is completed, there will be several hundred standards published. The Medical Service's first AFOSH standard on the Respiratory Protection Program was submitted to the Department of Labor and the unions for comments in August 1976. AFOSH standards on Asbestos, Vinyl Chloride, Industrial Ventilation, General Sanitation, and 14 Carcinogenic Substances are being prepared and they should be submitted for review shortly.

The Engineering and Services Directorate is attempting to determine the cost of modifying Air Force facilities to comply with the published standards. Yet to be accomplished is a determination of the cost of modifying any equipment that may have to be changed to comply with the standards. In addition to the direct impact, the indirect impact of these standards could be more significant, but it is extremely difficult to assess. The contractors may raise their prices for goods as a result of Occupational Safety and Health Act.

Even though the Air Force had an effective Safety and Health program, these new guidelines have impacts at base level. These include such things as reporting of occupational illness, surveying all workplace annually, and increased emphasis on the adequacy of records pertaining to workplace surveillance. However, the new proposed Department of Labor health standards indicate a much greater impact on our base level resources. The proposed standards generally increase the complexity of our present workplace surveillance and monitoring. There will be greater emphasis on documentation of the surveillance and monitoring. No longer will it suffice to rely upon ones past experience. We will require to take more samples more often. This will require additional manpower to comply.

The other aspect which may increase our base workload is involved with diagnosing and reporting occupational illnesses. Past experience has shown problems with the physicains diagnosing and relating illness to occupational exposures, administrative procedures and determining what constitutes a reportable occupational illness. We are not comfortable with the validity of this reporting. We are convinced that many occupationally induced illness are not being reported. This will require administrative changes and greater emphasis by the Medical Service. This problem, however, is not unique to the Air Force and is an issue that the Department of Labor and National Institute for Occupational Safety and Health will have to face.

The implementation of the Occupational Safety and Health Act has not proceeded as far as with the Environmental program. Although the laws were passed in the same time frame, the implementing Executive Orders for Occupational Safety Health Act did not impact the Federal Agencies until late 1974. Whereas the Environmental Executive Orders were effective in 1970 and 1971 with rewrites being published in 1973 and 1974. In order to make this program work, the Air Force will have to be exponents of total resources management and integrate research and fundamental science with engineering, medicine and planning. We will have to strive for comprehensive coordination of theoretical and practical know-how. The occupational safety and health program can only be tackled with a positive state of mind. We all have to be vitally concerned with the environment of the Air Force workplace. We can not succumb to human nature and rely on someone else to do the job for us.

ORGANIZATION

In order to comply with the Environmental and Occupational Health Programs, the Air Force Medical Service presently has approximately 221 Bioenvironmental Engineers, 24 health physicists, and 650 Environmental Health technicains assigned to these programs. In addition, approximately 25 civilian industrial medicine physicians are in special industrial health facilities and about 250 military physicians spend significant portions of their time in occupational health.

Due to the increasingly stringent monitoring and engineering control requirement and the need for additional occupational health examination, the following actions have been initiated by the Surgeon General:

(1) An Environmental Health Nurse Specialty was created to provide increased capability for conducting the clinical aspects of the occupational health program.

(2) 116 additional environmental health service personnel have been requested to provide for increased employee exposure monitoring, more comprehensive survey documentation and increased exposure data recordkeeping required to maintain consistency with Occupational Safety Health Act standards.

(3) The consolidation of the three Environmental and Radiological Health Laboratories into the USAF Occupational and Environmental Health Laboratory at Brooks AFB, Texas, to improve effectiveness and efficiency.

Within the Department of Defense, they have realigned responsibilities and now there is one primary Department of Defense staff responsible both for the environmental and occupational health and safety program. It is the Deputy Assistant Secretary of Defense for Environment and Safety, Office of Assistant Secretary of Defense for Installation and Logistics. The same is true in the Office of the Secretary of the Air Force. The Special Assistant for Environmental Quality is also responsible for both the environmental and occupational safety and health program.

Within the Air Force, Engineering and Service is responsible for pollution abatement and the compliance with the National Environmental Policy Act. The Surgeon General is responsible for environmental standards and compliance monitoring. In regard to the Occupational Safety Health Act program, the Surgeon General is responsible for the occupational health program and the Inspector General is responsible for the occupational safety program in the latest revision of AFR 127-12.

## CONCLUSION

I would like to conclude with several observations. The Air Force's primary mission is to fly airplanes and launch missiles in the defense of our country; but we are also dedicated to accomplishing this mission without contaminating our environment or causing injury and illness to our personnel. Therefore, we are having to take a deep look at the problem and allocate funds for environmental protection and occupational safety and health in competition with many other critical programs. There is the requirement to accomplish the job at a lower cost. Air Force Research and Development will provide valuable contributions and should be pursued as a modest program. This is where changes will have to be made to accomplish the job. However, this can only assist in the solution, remedial programs will leap forward only if they withstand the test of social, economic and political realities.

As a final note, I feel that we must place ourselves in the proper frame of mind. The environment must be protected and man's workplace has to be safe and healthy. We all have to do something about it.

We must acknowledge that our way of life and our way of doing business are going to change.

## DISCUSSION

**Purnell, UK**

Does current US legislation or guide lines give directives regarding audiometry particularly the need for routine surveillance.

**Author's reply**

The current US legislation and guidelines do not direct the use of audiometry in the surveillance program. However, the proposed rule making being considered by the Department of Labor would mandate routine monitoring audiometry. The Air Force has had routine monitoring audiometry as part of its hearing conservation program since 1956.

# OCCUPATIONAL HAZARDS OF MISSILE OPERATIONS WITH SPECIAL REGARD TO THE HYDRAZINE PROPELLANTS

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## SUMMARY

The second generation of ballistic missiles and boosters, characterized by increased range and quick reaction capability, required the development of new high energy storable propellants. This exploration led to the introduction of hydrazine (Hz), monomethylhydrazine (MMH), and 1,1-dimethylhydrazine (UDMH) into the United States Air Force inventory. These compounds are all storable, non-cryogenic, high energy fuels which may be used alone or in combination as mixed amine fuels. Further, hydrazine and its derivatives are finding increasing commercial application as intermediates in the synthesis of other products. Hence, substantial quantities of these agents are presently manufactured, stored, and shipped in the USA. The materials are all quite toxic and present a potential hazard for personnel who handle or are in contact with them under any and all use conditions. In addition, they may pose a hazard to the general population if accidentally released into the general environment as a result of missile malfunction or transportation mishap. Consequently, propellant toxicology has become one of the major areas for USAF research in toxicology. Early work was designed to produce data on the acute and subacute effects of the propellants in order that standards could be propagated for test and operational procedures to protect propellant handlers. The early work indicated that despite similar chemical characteristics there were marked differences between the compounds in terms of toxicological mechanisms. All of the compounds produce different levels of central nervous system irritation (convulsions) as well as eye, skin, and respiratory tract irritation. The magnitude of these effects varies widely among the three, and two have rather unique actions. Hydrazine can cause hemolytic effects in man and animals. Experimental studies have indicated that the convulsant action of UDMH and MMH can be aborted by the use of Vitamin B6 though the agent is ineffective against hydrazine toxicity. Since the propellants and some systems have been in use for some 15 years, the emphasis on toxicology has been centered on the more chronic effects. Of further concern is an increasing body of evidence from some animal experiments that hydrazine and some of its derivatives as well as MMH and UDMH may possess oncogenic potential as well as chronic systemic effects.

With the advent of new occupational safety and health standards required for potential carcinogens as advocated by the Environmental Protection Agency and the Occupational Safety and Health Administration, it has become mandatory to produce data which can be useful in the evaluation of oncogenic potential for the hydrazines. This presentation will address itself to data leading up to present standards such as the Threshold Limit Value, Emergency Tolerance Criteria, Criteria for Short-Term Exposure to the Public, and oncogenic potential of these hydrazines.

## INTRODUCTION

The recent rapid advances in aerospace technology have brought about an increasingly complex chemical environment in which man must operate effectively in the research laboratory, in the giant governmental and industrial field complex, and in the relatively new environments of space and deepest oceans. Chemists and materials engineers are spawning new chemicals and new uses for old chemicals at a rate infinitely faster than toxicologists, pharmacologists, and industrial hygiene and industrial medicine personnel can cope with the many-faceted problems presented by these compounds. The second generation of ballistic missiles and boosters, characterized by increased range and quick reaction capability, required the development of new high energy storable propellants. The Department of Defense, the National Aeronautics and Space Administration, and the Federal Aviation Agency, as well as many private and industrial concerns, have been instrumental in sponsoring a great deal of research in the areas of propellants, fuels, oxidizers, and other chemicals of use. Unfortunately, the price for increased energy content has been increased reactivity and biological activity. Consequently, propellant toxicology has become one of the major areas for United States Air Force (USAF) research in toxicology. To understand and properly evaluate the health hazards peculiar to a certain propellant, or indeed any chemical compound, its pharmacological properties must be investigated, the pathways of metabolism, absorption, distribution, excretion, the type and magnitude of pathology established, and diagnostic and therapeutic methodology must be developed. Based on these parameters, tolerance criteria can be recommended for personnel who handle and are in contact with these compounds under any and all use conditions.

Another major area of research concerns environmental pollution that results from large scale and extended propellant and motor test operations. In this instance, other byproducts of propellant usage become increasingly important. Combustion products, motor exhausts, chemically treated wastes, and reaction products with the environment all possess potential toxicity to animal and human life, vegetation, and soil microflora. The most important implication is pollution of community air and water around large scale industrial research and development operations. The sources for such pollution are either acute (large spills, transportation accidents, waste disposal, test firing of motors) or cumulative (venting and flare-off of propellant vapors, routine decontamination procedures, long term operations). Evaluation of the environmental pollution profile of a specific propellant operation requires both controlled experimental laboratory studies and on-site field investigations using mobile analytical laboratories.

Two major problem areas are peculiar to aerospace operations. The first is the type of exposure that is usually encountered by USAF personnel. Contrary to the industrial type of exposure during the production of propellants, where daily low level frequent exposure occurs and industrial Threshold Limit Values (TLV) are applicable for protective purposes, most of the field operations are characterized by short duration, high level infrequent exposures that are generated by test activities or by accidental release of propellants. Under the latter circumstances, TLV's are meaningless and become extremely difficult to live with. In the past few years, much research effort has been expended in characterizing tolerance to high level, short duration exposure, and in establishing Emergency Exposure Limits (EEL) for missile operators.

The establishment of scientifically valid and safe EEL's requires extensive animal experimentation, highly specialized inhalation facilities, and the application of psychopharmacological principles in addition to the classical pharmacological and toxicological methods. The philosophy of emergency exposure is predicated on three cardinal assumptions: (a) nobody will be intentionally exposed to high concentrations of propellant vapors under ordinary circumstances; (b) if exposed, subjective and objective symptomatology may occur but pathology should be reversible; and (c) while discomfort and pathology are tolerable, performance of the operator must not be impaired. On the basis of animal and any human exposure data available, EEL's are recommended by either the American Conference of Governmental Industrial Hygienists or by the Committee on Toxicology, National Research Council of the National Academy of Sciences.

Of course, in the establishment of the TLV or EEL increasing emphasis has been placed on the possibility that a compound may possess teratogenic, mutagenic or oncogenic potential. A large amount of very expensive and time consuming effort is being expended in this regard.

Inasmuch as the literature is quite voluminous concerning the toxicology and pharmacology of the propellant hydrazines, this paper will deal only with pertinent information published since 1970. For details of earlier data one is referred to two comprehensive review articles.[1,2] The most recent review of health hazards from hydrazine (Hz), monomethylhydrazine (MMH), and 1,1-dimethylhydrazine (UDMH) was accomplished by the Committee on Toxicology, National Research Council of the National Academy of Sciences and published in June 1974.[3] We are in complete agreement with the findings and interpretations in this document which very adequately covered animal toxicity data; absorption, distribution, and excretion; effects on metabolism and enzymes; target organ effects and tissue pathology; carcinogenicity and mutagenicity; human health effects and therapy of intoxication. The document also contains an extensive and excellent list of references from the United States and world scientific literature.

## NEW DEVELOPMENTS IN THE TOXICOLOGY OF THE HYDRAZINES

The most significant impact of the recently completed and currently on-going research is in the area of safety margin for Threshold Limit Values (TLV) and oncogenic potential of the three hydrazine propellants:

a. The safety margin for the hydrazine TLV was tested by inhalation exposures in animals and was found nonexistent.[4,5] As a result, the TLV committee has already tentatively lowered the hydrazine TLV from 1.0 ppm to 0.1 ppm in the 1975 pamphlet under "Notice of Intended Changes." Although our referenced experiments were not designed as oncogenic studies, mice kept for one year postexposure observation have shown a dose dependent increase in alveolargenic carcinomas when compared to controls. This finding coupled with other reports from the literature (feeding studies) has also placed hydrazine on the A2 list of "Occupational Substances Suspect of Oncogenic Potential for Workers."[6]

b. UDMH has also been implicated to be tumorigenic by oral administration (in drinking water) in the mouse[7,8] but not in the rat[9] and no long-term inhalation exposure studies were done.

c. MMH has been similarly implicated to be tumorigenic in the hamster[8,10] when ingested in drinking water; however, a recently completed similar study using hamsters in our laboratories[11] failed to confirm the high incidence (43%) of Kupffer cell sarcomas observed by Toth.

d. There are no known cancer cases among hydrazine, MMH and UDMH propellant manufacturing and handling personnel as of today.

Because of the demonstrated oncogenic potential of all three hydrazine propellants in either the mouse or the hamster (but not in the rat) by the oral route in studies completed elsewhere, our observations on hydrazine exposed mice by the inhalatory route, and the recommendation of the Committee on Toxicology, National Research Council of the National Academy of Sciences report[3] that "additional research on the potential carcinogenicity of these compounds should be conducted," definitive oncogenic dose-response studies have been initiated in our inhalation exposure facilities, using large numbers of mice, rats, and hamsters and a limited number of dogs (as biochemical indicators). The UDMH exposures have been completed, hydrazine is currently being studied and plans are in formulation for MMH exposures.

### A. Effects on Animals

#### 1. Acute Toxicity

Hydrazine (Hz), Monomethylhydrazine (MMH), and Unsymmetrical Dimethylhydrazine (UDMH)

Darmer and MacEwen exposed dogs, monkeys, and rats by inhalation to 1 ppm MMH for twenty-four hours.[12] No adverse effects were observed during the exposure, in the clinical chemistries obtained biweekly during the thirty-day postexposure period, nor in histopathological examination of the animals thirty days postexposure.

In preparation for the use of hamsters as one of the test species in oncogenic studies of the propellant Hz, inhalation studies were performed to determine the acute lethality to this species. The one-hour $LC_{50}$'s for MMH, UDMH and Hz were 991 ppm, 2271 ppm and 2585 ppm, respectively (MacEwen and Vernot, 1975).[13] All three compounds caused severe respiratory irritation and central nervous system effects. Convulsions were produced after exposure to MMH and UDMH but not following exposure to Hz vapors. However, exposure to Hz vapors, regardless of concentration, resulted in severe hair loss to hamsters. All three compounds cause significant lung, liver, and kidney damage, even at the lowest levels tested in this study.

These results indicate that although the hamster is less susceptible than the rat or the mouse, it reacts to toxic levels of these three compounds in a similar manner to that reported for other species.

2. Repeated Dose Toxicity

a. Monomethylhydrazine (MMH)

In an effort to determine a true no-effect level for chronic exposure to MMH, Darmer and MacEwen conducted continuous 90-day inhalation studies on dogs, monkeys, and rats.[12] At 0.1 ppm rat growth rates were significantly reduced although organ weights and organ to body weight ratios were not significantly altered. The dogs demonstrated significant increases in serum phosphorus and alkaline phosphatase values at this exposure level and were the only species to demonstrate gross pathologic changes characterized by nutmeg appearing livers. No adverse effects attributable to exposure were seen in the 0.04 ppm exposed animals. This study complemented a previous study by Haun (1970) where dose related toxic responses were observed in dogs, monkeys, rats, and mice exposed to 2 and 5 ppm MMH intermittently for six months.[14]

b. Hydrazine (Hz)

Results of six-month intermittent and continuous Hz inhalation exposures to mice, rats, dogs, and monkeys were reported by Haun and Kinkead[4] and MacEwen et al.[5] The doses selected for the intermittent (industrial regimen) study were 5 ppm and 1 ppm, the latter being the current TLV at that time. Doses for continuous exposure were 1.0 ppm and 0.2 ppm which approximately equalled the CT (concentration X time) values for the intermittent study. The hepatotoxic response in mice and the weight loss and anemia seen in the dogs resulting from exposure to the lower doses indicated that the 1.0 ppm TLV may be too high. A small group of mice was held for one year postexposure observation. Although the small number of animals precluded any statistical evaluation, the increased dose related incidence of alveolargenic carcinomas occurring in these mice suggested an oncogenic problem may be associated with chronic inhalation exposures to this compound.[5]

3. Effects on Metabolism and Enzymes

Hydrazine (Hz), Monomethylhydrazine (MMH), and Unsymmetrical Dimethylhydrazine (UDMH)

Dost using radiorespirometric techniques reported that subacute exposure to MMH causes a hyperglycemic response in intact animals which results from an interference with glycolysis in the hexose phase of anaerobic glycolysis. Glucokinase, hexokinase, and pyruvate kinase are all inhibited by MMH but the major inhibitory effect appears to be the phosphofructokinase step. Conversely, Hz produces a hypoglycemic response and Dost reported that the probable site of action occurs after pyruvate decarboxylation with an interference in the flux of the acetate fragment into fatty acid synthesis and eventual oxidation. Dost also confirms the inhibition of glycogen synthesis by hydrazine and indicates that the site of interference occurs after glucose-6-phosphate formation.[15]

These effects of MMH and Hz on glucose metabolism appear dose and time related; these studies represent high doses, 0.5-1.0 acute $LD_{50}$ given over periods of several hours to healthy normal animals. The effects were not observed at lower doses although the changes in glycolysis were evident when only part of the total dose was received.

Dost also reported MMH and Hz cause a decrease in methylamine and putrescine oxidation confirming previous work. MMH was more effective than Hz and methylamine oxidation was more sensitive to the inhibition by the Hz than putrescine.

Prough, Wittkop, and Reed (1969, 1970)[16,17,18] reported the presence of microsomal enzyme systems in rat liver capable of metabolizing MMH and UDMH. Two modes of metabolism were noted: an alkylhydrazine oxidase converting alkylhydrazines to corresponding alkanes and a N-methylhydrazine demethylase producing formaldehyde from the n-methyl group. These two systems were found, singly or both, in varying degrees of activity in several animal species. Studies were done to determine the relationship of these enzyme systems to microsomal redox components cytochrome $b_5$ and P450. The oxidase activity is not dependent on P450 and cannot be induced by phenobarbital or 3-methylcholanthrene. However, there appear to be two demethylase enzyme systems present in rat liver microsomes, one inducible and dependent on P450 and one not, both capable of demethylating N-methylhydrazines. Kato et al (1969) also reported MMH and UDMH can inhibit activity of drug metabolizing enzymes in liver microsomes and suggested their effectiveness of inhibition is related to the degree of lipid solubility of the individual hydrazines.[19] Roberge et al (1971) investigated the effect of Hz on urea cycle enzymes in vitro and in vivo. Ornithine ketoacid transaminase was inhibited provoking accumulation of ornithine. The high concentration of ornithine and increased ammonia production stimulates urea synthesis. The condensation reaction of citrulline and aspartic acid is rate-limiting for the urea cycle with resultant accumulation of citrulline.[20]

Hawks et al (1974) reported no inhibition of incorporation of amino acids into rat liver protein by UDMH or MMH.[21]

Dost et al (1971) reported Hz causes a two-fold increase in brain Gamma Aminobutyric Acid (GABA) as the inhibition of GABA transaminase was higher than the interference in GABA formation by decarboxylation of glutamic acid. MMH also strongly inhibits GABA transaminase whereas UDMH has only a moderate inhibitory effect.[22]

4. Tumorigenesis

Monomethylhydrazine (MMH)

MacEwen and Vernot (1975) attempted to confirm the oncogenic potential of MMH to hamsters when administered in drinking water. Thirty hamsters received 0.01% of MMH in drinking water adjusted to pH

3.5 with HCl; 30 hamsters received 0.01% MMH in drinking water not pH controlled; 17 hamsters served as controls. The study was conducted for the life span of the hamsters beginning at 5 months of age. No *significant increase in tumor incidence attributable to the MMH could be determined.*[11]

5. Mutagenesis

Hydrazine (Hz), Monomethylhydrazine (MMH), and Unsymmetrical Dimethylhydrazine (UDMH)

Wyrobek and London (1973) utilizing an in vivo mammalian test system involving examination of murine spermatogenesis evaluated the mutagenic potential of Hz, MMH, and UDMH. Groups of mice received doses of each compound ranging from 0.1-0.9 of the $LD_{50}$ for five days. They established both a dose and a dose-time relationship between injection of these compounds and the appearance of abnormal sperm.[23]

6. Effects on Behavior

Monomethylhydrazine (MMH)

Sterman (1975) conducted studies on the behavioral effects of MMH in the cat.[24] The influence of subconvulsive exposure was examined with reference to a more basic aspect of physiological function than previous sensorimotor and performance studies, namely the organization of sleep-waking patterns. Polygraphic recordings providing for classification of states of sleep and wakefulness were obtained over a 10-hour period following either saline or MMH (5 mg/kg, IP) injections. MMH caused no overt behavioral disruption on transient observation at this dose; however, analysis of polygraphic data disclosed a significant depression of sleep and disruption of normal diurnal rhythms. Sleep suppression lasted approximately six hours and was followed by a profound sleep rebound. The behavioral effects of MMH exposure extended beyond the realm of sensorimotor functions. The influence noted upon sleep could have equally serious and different consequences in performance. The effect of MMH upon thalamocortical conduction was also examined. Cats were operantly trained to suppress movement by rewarding a sensorimotor EEG rhythm (the SMR) with positive hypothalamic brain stimulation. Other cats received similar, but non-contingent, reward. Following training, the two groups were administered MMH (10 mg/kg, IP) and thalamically induced somatosensory evoked potential responses measured until seizures occurred. The non-contingent group showed an expected increment in response prior to seizures, while the SMR-trained cats showed a decrement or reduced increment. Sterman et al (1975) investigated the influence of intracranial electrode placement upon the seizure response to MMH.[25] Efforts were also made to replicate previous findings with regard to the effects of EEG operant conditioning on this response. Thirty cats were studied, 10 in each of three different experimental groups, all of which were exposed to 10 mg/kg doses of intraperitoneally administered MMH. The dependent variable was latency in minutes to generalized motor seizures. The three experimental groups were: (1) an unoperated group, (2) an operated group with cortical and subcortical electrodes, and (3) an operated group as in (2), but provided additionally with sensorimotor rhythm (SMR) EEG operant conditioning. The operated group without EEG conditioning showed a significantly reduced and more stable latency to seizures when compared to the other two groups. These findings suggested that (1) some aspect of the procedure associated with central nervous system electrode implantation increased susceptibility to MMH-induced seizures, (2) unoperated animals had individual differences in seizure susceptibility, but were significantly more resistant to MMH toxicity than operated animals, and (3) SMR-trained operated animals had individual differences in response to training, but were also more resistant to MMH toxicity.

B. Effects on Humans

Monomethylhydrazine (MMH)

The hemolytic response observed in dogs and the documented Heinz body formation in humans following acute MMH exposure led Weinstein and George (1972)[26] and George (1973)[27] to study the in vitro response of human red blood cells to MMH. These initial studies led to a preliminary conclusion that the hemolytic effect of MMH observed in vivo is caused either by a direct action of this oxidant on cell membrane which is not obvious on fixed morphological observation or by the effect of Heinz bodies on cellular integrity leading to a decreased cellular "deformability" and premature removal of the injured cells from the circulation by the spleen, or both. Later studies by George (1974) designed to measure direct effects of MMH on compartments of cell membranes, potassium flux, autoxidation of membrane lipids and alteration of membrane protein gave additional support to the thesis that the major mechanism of red cell destruction following exposure to MMH appears to be the physical presence of Heinz bodies in the red cell resulting in a decreased deformability of the cell and accelerated sequestration and destruction by the spleen.[28] Studies also indicated that any enzyme deficiencies such as lack of glucose-6-phosphate dehydrogenase, 6-phosphogluconic dehydrogenase, or glutathione reductase (which affects 2-10 percent of black males and 0.3 percent white males) would exaggerate hemolysis and prevent reversal of the response. Personnel with this sort of genetic red cell disease should not be exposed to MMH even though minimal. Weinstein et al (1975) compared morphologically the Heinz bodies formed by MMH and acetylphenylhydrazine (APH) and studied the relationship between these Heinz bodies and red blood cell deformability. Unlike APH-induced Heinz bodies, MMH-induced Heinz bodies show little affinity for the cell membrane and are free of the membrane when decreases in deformability are first detected. These results show that alterations in red cell deformability with oxidative injury may be unrelated to Heinz body-cell membrane interactions. Ultrastructural observations suggest that denatured hemoglobin diffusely distributed in the cytoplasm may polymerize into a loose network and account for the altered rheological properties of MMH-injured red cells.[29]

C. Effects on Non-mammalian Life Forms: Environmental Degradation and Effects on Aquatic Life

Aerozine 50 (50/50 mixture of Hz and UDMH) (Az-50), Hydrazine (Hz), Monomethylhydrazine (MMH), and Unsymmetrical Dimethylhydrazine (UDMH)

Hoover et al (1964) related aquatic decomposition rates of Hz and UDMH to the presence of oxygen, the presence of a catalyst such as copper, water temperature, and water pH.[30] These studies were expanded by Gormley and Ford (1973) to include MMH. Based upon a stoichiometric relationship between the amount of propellant degraded and the amount of dissolved oxygen (D.O.) in the water, first order rate constants were developed for copper catalyzed degradation of these propellants.[31] Lurker (1976) has used similar methodology to study in more detail the effect of other ions present in water and to better define the effect of temperature on degradation rates.[32] Slonim (1975) studied the effects of Hz, UDMH, Az-50, and MMH when placed in hard and soft water over a 96-hour period. At 100 mg/liter but not at 1 mg/liter, the hydrazines produced a transitory drop in the D.O. of hard water. The effects were not seen in soft water.[33] Slonim and Gisclard (1975) also developed a rapid and sensitive polarographic method for measuring Hz in solution. The method was used to study the stability or degradation of Hz over a 96-hour period in river, lake, pond, county, city, and laboratory water. Varying amounts of degradation of Hz were observed in many of these waters. Hz was relatively stable in soft water and softened city water.[34]

Heck et al (1962) exposed goldfish, daphnia, and dragonfly nymphs to Hz and UDMH during static, unreplenished bioassays. The 48-hour Hz $LC_{50}$ values were 3.2, 2.4, and 320 mg/liter, respectively. Natural pond water was the dilution water used. The UDMH was found to be about 1/10 as toxic since it produced 48-hour $LC_{50}$ values of 32 mg/liter for the goldfish and 24 mg/liter for the daphnia.[35] Heck et al (1963) in similar static bioassays extended their studies to include goldfish, green sunfish, small bluegill, large bluegill, channel catfish, and largemouth bass using dilution water containing 0.15 mg/liter copper. The 48-hour $LC_{50}$ for Hz varied from a low of 1.6 mg/liter in the catfish to a high of 5.2 mg/liter in the large bluegill. The 48-hour $LC_{50}$'s for UDMH were much higher, ranging from 16.5 mg/liter for small bluegill to 58 mg/liter in goldfish.[36]

Hoover et al (1964) performed static bioassays using goldfish, catfish, bass, and daphnia to study the toxicity of Hz and UDMH in "copper free" (<.01 mg/liter $Cu^{II}$) water. His results were not significantly different from those produced by the low copper concentrations in Heck's dilution water.[30]

Heinemann and Rose (1966) conducted bioassays using two marine species to determine the toxicity of Az-50. The 72-hour $LC_{50}$ for sheepshead minnows was 5.1 mg/liter. For grass shrimp the 72-hour $LC_{50}$ was 0.78 mg/liter.[37]

Slonim (1976) compared the toxicities of Hz, UDMH, MMH and Az-50 to guppies in hard and soft water. With the exception of UDMH, all were more toxic in soft than in hard water. The $LC_{50}$ values ranged from 0.6 mg/liter for Hz in soft water to 26.5 mg/liter for UDMH in soft water.[38]

Greenhouse (1976) studied the effects of Hz, MMH, and UDMH on amphibian embryos and larvae. He used the South African clawed toad, *Xenopus laevis*. Hz was not acutely toxic to post-hatching larvae in concentrations up to 400 mg/liter. However, Hz is teratogenic at 40 mg/liter if exposure occurs prior to the completion of neurulation. UDMH at 10 mg/liter was teratogenic to all embryonic stages whereas 100 mg/liter was lethal.[39]

The effect of these propellants has also been studied in aquatic plants. Heck et al (1963) grew *Chlorella* in varying concentrations of Hz and UDMH to observe the effects on growth. Concentrations of 1, 10, and 100 mg/liter were compared with the controls. All concentrations of Hz had an inhibitory effect with the 100 mg/liter concentration producing a complete cessation of growth. The 1 and 10 mg/liter concentrations of UDMH had little effect while the 100 mg/liter produced some inhibition.[36] Sherfig et al (1976) studied the effects of Hz and UDMH on the growth of *Selenastrum capricornutum*. Hz in concentrations of 10 µl/liter produced an algal cell volume growth of only 14 percent of the control growth. UDMH at 10 µl/liter reduced the growth of algae to about one-half of the growth of the controls. In contrast, the addition of low levels of UDMH (1 µl/liter) resulted in an increase in algal growth which was probably the result of a nutrient effect. Hz appears to be much more toxic by inhibiting growth of the test algae than UDMH.[40]

D. A 6-Month Chronic Oncogenic Study of 1,1-Dimethylhydrazine (UDMH). Status Report.

Reported here are the results of completed 6-month exposures of animals to 5 ppm, 0.5 ppm, and 0.05 ppm UDMH and non-treated controls.

Animals used in this study consisted of 400 female C57 black mice obtained from Jackson Laboratories, 200 male CDF (Fischer 344 derived) albino rats from Charles River, 200 male Engle Golden Syrian hamsters, and beagle dogs, 4 male and 4 female per group. A separate set of control animals was provided for the 0.05 ppm test since it was not started at the same time as 5 ppm and 0.5 ppm experiments. Two chambers were used for each UDMH air concentration. Each pair of chambers contained as few species as possible to minimize risk of cross infection. Dogs and rats were housed in one dome and mice and hamsters in the companion chamber. All control animals were maintained in animal holding facilities.

The Thomas Domes in the Toxic Hazards Research Unit (THRU) were operated with nominal airflows of 35 CFM at a slightly reduced pressure of 725 mm Hg to prevent leakage of UDMH into the laboratory. Exposures were conducted on a 6 hour/day, 5 day/week schedule. No exposures were made on weekends and holidays.

The control of potential carcinogens in cancer research laboratories is essential for the prevention of occupationally acquired cancer and for the protection of the general environment from exposure to potential cancer inducing materials. Since the consequences of laboratory exposures to experimental carcinogens may not be demonstrated for many years, preventive measures, National Cancer Institute Safety Guidelines were followed in the conduct of this study. To this end then, special memoranda were posted in the laboratory and warning signs were placed at all access doors. The exposure laboratory was off limits to visitors and staff personnel not actually involved in the conduct of the study. The tasks of the technicians involved entries into the chambers following the completion of the daily exposures. Protective clothing used were coveralls, hoods, gloves, and boot covers. All of this equipment is disposable paper or plastic and was discarded daily in sealed plastic bags. Air supplied full face masks were used for respiratory protection. All technicians showered after the last dome entry. Analytical measurements made by the THRU Chemistry Department provided assurance that UDMH concentrations were extremely low or nonexistent in the UDMH generation hoods, in the laboratory spaces adjacent to the chambers, and in the effluent air and vacuum pump water.

The chamber concentrations of UDMH were generated and continuously monitored with apparatus and instrumentation essentially the same as used for chronic hydrazine and MMH studies in the past. Details may be found in previous reports (Haun, 1970; MacEwen et al, 1974).[14,5]

All test animals were observed hourly during exposure and non-exposure periods for signs of UDMH intoxication and mortality. Gross and histopathologic examination was made on all dead animals. Rats, hamsters, and dogs were weighed individually at biweekly intervals during exposure and monthly during the postexposure period. Mice were weighed in groups and group mean weights followed on a monthly basis throughout the experimental period. Blood samples were drawn from dogs at biweekly intervals and clinical determinations made for the following battery of tests:

| | | | |
|---|---|---|---|
| RBC | Sodium | Differential Cell Count | Albumin |
| WBC | Potassium | Total Protein | Globulin |
| HCT | Calcium | Alkaline Phosphatase | SGPT |
| HGB | Glucose | | |

Blood measurements not included in regular biweekly schedule during the exposure phase of the study but made at the conclusion of the 5 ppm, 0.5 ppm, and 0.05 ppm experiments were:

| | |
|---|---|
| Blood urea nitrogen | SGOT |
| Chloride | Prothrombin time |
| Cholesterol | Cephalin flocculation |
| Creatinine | Bromsulphalein |

Of these, tests giving abnormal values were scheduled to be repeated postexposure at regular intervals until recovery. To examine for possible hemolytic effects in rodents, blood samples for hematocrit and red blood cell counts were taken from 5 rats and 5 hamsters from each group at the conclusion of the exposures. Blood was withdrawn using a nondestructive suborbital technique. No alterations attributable to exposure were noted in these determinations.

Overt signs of UDMH toxicity were nonexistent in animals exposed for 6 months to 5 ppm and 0.5 ppm UDMH. Growth curves for both groups of dogs and mice were normal when compared to those of the control groups. In the case of the rats, however, statistically significant lower weight-gain rates were noted for both exposed groups throughout the 6 months of exposure. Hamster weights were somewhat erratic and showed no weight gain when mean weights at exposure conclusion were compared with initial weights. Their mean weights with one exception (the 5 ppm exposed group at 4 weeks of exposure) were significantly lower than control during the entire exposure period. Effects on weight of exposed rats or hamsters were not dose dependent.

The numbers of animals that died during the 6 months of exposures are shown below.

MORTALITY RATIOS IN CONTROL AND UDMH EXPOSED ANIMALS

| Experimental Group | Dogs | Rats | Mice | Hamsters |
|---|---|---|---|---|
| Control | 0/8 | 52/200 | 31/400 | 103/200 |
| 0.5 ppm | 0/8 | 3/200 | 19/400 | 97/200 |
| 5 ppm | 0/8 | 3/200 | 24/400 | 84/200 |
| 0.05 ppm | 0/8 | 2/198 | 19/396 | 25/189 |
| Control* | 0/8 | 2/200 | 28/371 | 6/200 |

*Extra control group needed due to delayed start of 0.05 ppm experiments.

The mortality figures for both exposed and control hamsters can be misleading. In no case was death attributed to UDMH exposure. Early deaths were due to pneumonia, and particularly injuries from manipulation of cage catch pans during cleaning operations early in the study. This problem was eliminated by relocation of the hamster cages where catch pans were not required. Later deaths were due to normal aging processes. Death in groups of exposed and control mice were approximately the same; therefore, no toxicological significance is attached to mortality in exposed mice. The high mortality rate in the control rats was due to a pneumonia epizootic which occurred soon after exposure termination.

Results of clinical chemistry tests made on dogs biweekly during and following exposure were all normal except for serum glutamic pyruvic transaminase (SGPT) values shown below. It can be seen that SGPT values were significantly elevated in dogs exposed to 5.0 ppm UDMH after the first biweekly sampling period. A sharp reduction, approximately 50%, occurred at 2 and 4 weeks postexposure. Recovery was complete by 6 months postexposure.

MEAN SGPT VALUES† FOR GROUPS OF 8 BEAGLE DOGS EXPOSED FOR 6 MONTHS TO UDMH

| Weeks of Exposure | Control | 0.5 ppm | 5 ppm |
|---|---|---|---|
| 2 | 25.8 | 35.3* | 32.4 |
| 4 | 26.8 | 34.5* | 78.6** |
| 6 | 26.9 | 32.8 | 102.4** |
| 8 | 24.5 | 37.0* | 118.0** |
| 10 | 26.4 | 32.0** | 118.0** |
| 12 | 30.8 | 33.3 | 115.5** |
| 16 | 22.0 | 33.4** | 87.8** |
| 18 | 22.8 | 26.6* | 106.5** |
| 20 | 22.5 | 25.6 | 99.3** |
| 22 | 19.8 | 28.1** | 97.0** |
| 24 | 21.5 | 31.0* | 100.3** |
| 26 | 24.5 | 26.5 | 86.3** |
| Weeks Postexposure | | | |
| 2 | 22.1 | 24.5 | 36.6** |
| 4 | 22.5 | 27.6* | 41.6* |
| 26 | 33.0 | 36.3 | 30.1 |

† International Units.
* Significant at the 0.05 level.
** Significant at the 0.01 level.

Special liver function tests were performed on dogs at exposure termination. Prothrombin time and cephalin flocculation values were normal but bromsulphalein (BSP) measured in blood of the 5 ppm exposed dogs 10 minutes following 10 mg/kilo injection showed significant retention. This test was repeated at 4 weeks postexposure with similar results. However, BSP values all returned to normal 9 months postexposure. All BSP values are shown below.

MEAN BROMSULPHALEIN RETENTION VALUES* IN CONTROL AND UDMH EXPOSED DOGS

| Time | Control | 0.5 ppm | 5 ppm |
|---|---|---|---|
| Exposure Termination (26 Weeks) | 18.1 | 18.5 | 30.3** |
| Post Exposure (4 Weeks) | 20.7 | 16.8 | 29.5** |
| Post Exposure (9 Months) | 11.4 | -- | 12.3 |

* Percent retention.
** Significantly higher than controls at the 0.05 level.

Hepatotoxicity as measured by SGPT serum levels has not been demonstrated in the 0.05 ppm dog exposure group. All clinical measurements are normal and show no trends to adverse effect. Mean body weights of dogs and mice are comparable with controls while weights of rats and hamsters are approximately 3% less than their control groups. These differences are statistically but not biologically significant.

The desired daily UDMH concentration levels of 5 ppm, 0.5 ppm, and 0.05 ppm were maintained with good precision during the entire six months of the study.

Since a significant number of hamsters have died in both experimental and control groups, livers for the 5 ppm exposure group and their controls were examined for evidence of liver damage. The following is the preliminary histopathological report.

Common findings routinely seen in the liver of normal adult to aged hamsters are: (1) biliary cysts, (2) portal fibrosis - often seen in association with chronic triaditis and amyloid deposition, and (3) cholangial fibrosis and scarring seen in association with ruptured biliary cysts.

The predominant liver lesions seen in hamsters exposed to 5.0 ppm UDMH is triaditis, which is chronic and mild to moderate in severity, with 68% animals affected and biliary cysts with 36% of the animals affected (N = 44). These same lesions occurred in hamsters exposed to 0.5 ppm UDMH. Triaditis occurred in 73% of the hamsters. Biliary cysts occurred in 17% (N = 41). Hamster controls to these experiments had similar lesions in the liver. Triaditis occurred in 88% of control animals, and biliary cysts were seen in 24% of control animals (N = 33).

The liver lesions seen in the animals that have died prematurely on these experiments are consistent with those seen in adult hamsters. The predominant cause of death in both experimental and control animals is kidney dysfunction due to renal glomerular amyloidosis. This is a common cause of death in adult to aged hamsters. There has been no disproportional death loss in any of these groups.

Significant exposure effects of UDMH were limited to slight to moderate hepatotoxicity in dogs exposed to the 5 ppm concentration with recovery 6 months postexposure. No toxic effects have been observed in the 6 month 0.5 ppm or 0.05 ppm exposed animals. On the basis of results of tests and measurements used in this study, the current industrial TLV of 0.5 ppm UDMH appears to be well chosen without consideration of cancer risk. Cancer incidence will be assessed during the lifetime observation and testing of the rodents and dogs.

Necropsy and histopathology schedules will allow for completion of necropsy by September 1976 with target date for final report by May 1977. The histopathology will be processed using the National Cancer

Institute protocol which calls for a minimum of 30 tissue from each animal. Tumor data will be computerized for each species by dose.

As stated previously, hydrazine is currently being studied using a slightly different protocol and plans are being formulated for monomethylhydrazine. The hydrazine protocol uses four dose levels of 5.0, 1.0, 0.25, and 0.05 ppm and exposure will be for one year followed by lifetime holding.

E. Occupational Medicine and Industrial Hygiene Guidelines

1. Airborne Concentrations/Acute Exposures

a. Military and Space Operations

EMERGENCY EXPOSURE LIMITS (EEL)

| | 10 min | 30 min | 60 min | 24 hrs |
|---|---|---|---|---|
| Hydrazine | 30 ppm | 20 ppm | 10 ppm | -- |
| Monomethylhydrazine | 90 ppm | 30 ppm | 15 ppm | 1 ppm |
| 1,1-Dimethylhydrazine | 100 ppm | 50 ppm | 30 ppm | -- |

b. Industrial and Production Plants

SHORT-TERM PUBLIC LIMITS (STPL)

| | 10 min | 30 min | 60 min |
|---|---|---|---|
| Hydrazine | 15 ppm | 10 ppm | 5 ppm |
| Monomethylhydrazine | 9 ppm | 3 ppm | 1.5 ppm |
| 1,1-Dimethylhydrazine | 50 ppm | 25 ppm | 15 ppm |

PUBLIC EMERGENCY LIMITS (PEL)

| | 10 min | 30 min | 60 min |
|---|---|---|---|
| Hydrazine | 30 ppm | 20 ppm | 10 ppm |
| Monomethylhydrazine | 90 ppm | 30 ppm | 15 ppm |
| 1,1-Dimethylhydrazine | 100 ppm | 50 ppm | 30 ppm |

2. Airborne Concentrations/Chronic Exposures

OCCUPATIONAL THRESHOLD LIMIT VALUES (TLV)

| | | |
|---|---|---|
| Hydrazine* | 0.1 ppm | "Skin" |
| Monomethylhydrazine | 0.2 ppm | "Skin" |
| 1,1-Dimethylhydrazine | 0.5 ppm | "Skin" |

*Suspect carcinogen.

3. Direct Contact

a. All three propellant hydrazines penetrate the eye and the skin readily if not immediately flushed away with copious amounts of water for 15 minutes. Failure to promptly remove the chemical may result in systemic toxicity.

b. Always wear approved protective equipment to avoid direct contact.

4. Biologic Standards

a. For occupational (at the TLV level) exposures, there are no biological indicators, such as blood or urinary levels of the hydrazines or their metabolites that could be used at the present for monitoring the workers who are <u>not</u> suffering ill effects. Because of the relatively fast clearance rate of hydrazines from the body, no accumulation of the propellants or their metabolites is expected within the detectable range using current techniques and analytical procedures suitable for monitoring the working population.

b. In acute exposures at the EEL levels, monomethylhydrazine can cause Heinz body formation in the red blood cells, up to 5% after seven days postexposure to 90 ppm for 10 minutes. Under these circumstances there is no measurable methemoglobin formation and hence, the exposure is not considered to be of medical consequence.

5. Engineering Controls/Personal Protection

For handling propellant hydrazines one should consult Department of the Air Force Manual, Volume II, AFM 161-30, titled "Aerospace Medicine: Chemical Rocket/Propellant Hazards," dated 10 April 1973.

6. Medical Examination of Workers/Preemployment and Annual

a. Complete physical examination (Class III Flight Physical).

b. Laboratory tests should include pulmonary function and chest X-ray, hematology, liver function, kidney function, and EEG.

c. Contraindications for working with hydrazine propellants should include pregnancy, anemias and hematologic disorders, history of convulsive episodes and other neurologic disorders, "slow acetylators", glucose-6-phosphate dehydrogenase deficiency, 6-phosphogluconic dehydrogenase deficiency, glutathione reductase deficiency, therapeutic use of tranquilizers, and the existence of "benign" tumors.

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The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animal," DHEW 73-23.

# THE USE AND CONTROL OF HAZARDOUS MATERIALS IN AIRCRAFT MAINTENANCE

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## INTRODUCTION

The construction of modern airliners is highly complex utilising a wide range of components and calling for many, often sophisticated, maintenance functions. Consequently many materials are used both in the construction and maintenance activity. These materials can expose airline maintenance personnel to a variety of potential hazards although evidence of serious harm resulting from their use is rare.

Metals, acids, alkalis, gases, solvents, stripping agents, paints, plastics, resins, foams, fabrics and fuels are among the materials handled and this brief list gives some indication of their nature and diversity.

Tracing the use of potentially hazardous materials is complicated by the fact that similar chemicals may be found in a wide variety of uses, locations and processes, and often a potentially hazardous chemical is found only as a constituent of a mixture or compound, identified only by a trade name which gives no indication of the chemicals involved.

## MODE OF ACTION AND TOXICOLOGY

A detailed account of materials used in aircraft maintenance is not possible in this paper, neither can their toxicology be discussed in detail. However, the salient problems are as follows:

Many of the materials listed above may have irritant or sensitising effects on the skin, conjunctivae and mucous membranes or may enter the body by these routes. Those materials which are in the form of dusts, vapours or gases may have a direct effect on the respiratory tract or may enter the body via the pulmonary circulation. The hazard of accidental ingestion of chemical materials is an extremely unlikely event in aircraft maintenance although it should not be completely overlooked. For example, laboratory processes may involve the aspiration of chemicals and hand to mouth transfer of materials may occur in maintenance activities if the hands are not washed before meals or smoking.

Hydrocarbons in the form of solvents, thinners, and fuels, are among the most widely encountered chemicals and may cause skin irritation, dermatitis, and narcosis if inhaled in high concentrations. Acids and alkalis are obviously corrosive; some, like hydrofluoric acid, being highly destructive, and others, like phenol, having a toxic effect in addition to damaging surface tissues. Dusts, such as asbestos, may be fibrogenic and others, such as beryllium, may have specific pathological effects not confined to a single end organ. Resins, foaming agents and paints may contain physiologically active chemical groupings, in particular the isocyanate or epoxy groups which can give rise to skin and lung sensitisation.

Finally, although the subject has by no means been fully covered one may encounter metals such as cadmium and mercury, as well as metallic salts, which have diverse and complex toxicological effects involving several end organs.

## CONTROL

### General Principles

The principles of toxic material control involve the use of the least hazardous material compatible with technical requirements, containment, local exhaust ventilation and the avoidance of direct handling. In addition, there will need to be good general standards of ventilation and housekeeping, safe methods of work, and the use, where necessary, of protective clothing and equipment.

Materials control procedures require a system of communication enabling materials to be identified, their hazards evaluated and brought to the attention of management and employees, and the necessary safeguards established, communicated and inplemented. Two measures developed in British Airways as part of the control and communication process will now be described.

### 1. MATERIALS CONTROL

#### Procedure

To acquire chemically based or raw materials the requisitor must complete a New Materials Request Form which is returned to a "Quality and Reliability" department. This department determines whether the material is necessary and is technically suitable. If they are satisfied technically that the acquisition of the material should be approved the request is next forwarded to the British Airways Medical Service for hazard evaluation and for the material to be given a health hazard classification; rarely a material may be rejected as undesirably toxic or a safer substitute suggested. Finally, the Fire Protection Branch evaluate the fire risk and allocate a 'Fire Risk' classification. On satisfactory completion of these procedures, purchase approval is given by the Quality and Reliability Department and the material is included in an Approved Materials List showing, against the name of the material, the hazard and fire classification. Where necessary, any restrictions on use or any special precautions are indicated in a 'Remarks' column.

No material may be used or acquired unless, or until, it is included in the Approved Materials List.

## Hazard Classification

The health hazard classification is a simple one. The health hazards are defined by a two letter symbol. The first letter indicates the principal area of the body where the material can exert its effect.

i.e. S Skin

E Eye

B Breathing - Inhalation of fumes, gases, vapours

M Mouth - Ingestion, whether accidental or deliberate.

The second letter (actually a digit) indicates the potential severity of the health risk:

i.e. 1 Moderate Risk e.g. from prolonged or heavy exposure

2 High Risk e.g. immediate or severe effects.

Thus S1, for example, indicates a material with a moderately severe effect on the skin such as the irritation which may occur on exposure to hydraulic fluids.

## Precautions

In an introductory section of the Approved Materials List the general precautions relevant to a particular classification are indicated. So, for example, against S1 the following precautions are shown:

"Apply barrier cream before starting work. (specific creams are stipulated for a few processes otherwise use the general purpose barrier cream).

Keep skin clean by regular washing. At work approved hand cleansers are supplied. Always wash hands thoroughly before eating, drinking, smoking or using the toilet.

Avoid unnecessary contamination of the skin. Protective clothing, for example, gloves, may be indicated."

## Emergency Action

Another introductory section relates the classification to recommended emergency action in the event of exposure. Continuing the example of a material classified as S1, the emergency action section reads as follows:

"Contaminated parts should be thoroughly washed and rinsed; re-apply barrier cream.

Resins may be removed from the skin using Kerodex 22 skin cleanser.

If soaked in kerosene, oil, chemical solution etc:-

Do not continue working in heavily contaminated overalls.

Report to nearest Occupational Health Unit for use of bath or shower facilities and loan of clean undergarments and overalls.

ALWAYS REPORT SKIN IRRITATION, SKIN RASHES, SKIN WARTS, SKIN ULCERS, TO MEDICAL STAFF - NEVER BE SHY ABOUT DOING SO."

The Approved Materials List is available to all employees in the relevant working locations.

## 2. PROCESS CONTROLS

In addition to the identification, evaluation and control of materials generally, it is necessary to establish more detailed control procedures in respect of certain processes in which the materials may be used. Major processes are again as diverse as the materials used in them; ranging, for example, from the electro-plating of components to the repair of fuel tanks or aircraft painting. Major processes are detailed in a Process Specification Manual and when the technical requirements of the process have been established the draft Process Specification is forwarded to the medical service for inclusion of any necessary precautionary advise against hazards. Frequently this is relatively simple and routine but in some cases the medical service may be closely involved in the early stages of the development of a process to ensure that potential hazards are evaluated in advance and overcome before the process is brought into operation.

Thus, when any process involves a health or safety hazard the Process Specification document will contain, normally at the beginning, a section dealing with the health and safety precautions. Where the process is summarised schematically in addition to the main text, the schematic chart is prefaced along the following lines:

e.g. "Process Sequence

Prior to commencement of solvent degreasing it is imperative that the operator shall read notes 1-7. Note 1 concerns your health and safety.

## CONCLUSION

There are many ways of controlling potential health hazards in industry. No single method is likely to suffice particularly in the airline industry where the activities and potential risks are so diverse.

Two methods in use in British Airways have been described but these represent only part of the total picture of materials control. However, it should be noted that while the activities and materials involved in aircraft maintenance are many and the controls complex, the diversity of the operation so often means that exposure to toxic hazards are infrequent and often minimal. Nevertheless, reliance on such a premise is likely to prove dangerous. Constant vigilance, backed by adequate controls is the wiser course.

My thanks are due to Dr. J. Graham Taylor, Director of Medical and Safety Services, British Airways Medical Service, for permission to publish.

## DISCUSSION

**Air Cdre J.N.C.Cooke, UK**

Would you give the sources from which you gain toxicity information on new industrial products. How do you monitor the possible appearance of unexpected toxic effects and what action is taken?

**Author's reply**

The manufacturer is asked to give information on the composition and toxicology of his product and from this we make our own assessment using the usual literature sources for information. The product is then given a health hazard classification in the Approved Materials list and other information provided to our users as described in the paper.

In general we use materials whose toxicity is well documented but of course unexpected hazards may occur even in these circumstances. We maintain a constant vigilance of the literature and of our working environment and employees. From these sources we expect to obtain early warning of new problems and take whatever preventive action is appropriate.

# OCCUPATIONAL HEALTH HAZARDS ASSOCIATED WITH AIRCRAFT SHELTER OPERATIONS

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## SUMMARY

The concept of operations from shelters is to provide protection for the aircraft from surprise attack whilst on the ground. The design features of shelters, which are intended to give a reasonable probability of survival of the aircraft and maintain an operational capability, are those which also fulfil the criteria for a confined space. The occupational health hazards to personnel employed in shelter operations therefore are essentially those associated with aircraft operations qualified by the restrictions applicable to a limited work-space.

Potential hazards are identifed as those arising from the turbine engines of aircraft and those arising from both turbine and petrol engines of ground support equipment necessary for front line maintenance. These are noise, fuel vapour and exhaust pollutants.

Environmental levels of the pollutants under typical operations are compared with current threshold limit values. Recommendations are made for:

(1) reduction of exposure

(2) permissible excursions above current threshold limit values for specific pollutants

(3) biological monitoring of exposed personnel

## INTRODUCTION

The purpose of aircraft shelters is to provide protection for the aircraft whilst on the ground, from surprise enemy attack. The design features are intended to give a reasonable probability of survival of the aircraft to maintain an operational capability.

The current concept is that aircraft will operate from shelters at all times, and except for movement of aircraft the shelter doors will remain shut. We are therefore assessing an occupational health problem of aircraft maintenance in a restricted work space, and aircraft operation (i.e. engine start and taxying) in a relatively confined area.

## POTENTIAL OCCUPATIONAL HEALTH HAZARDS

The main sources of pollution creating potential occupational health hazards to personnel are:

Refuelling of aircraft

Ground support equipment

Aircraft engines

### Refuelling of Aircraft

Refuelling of aircraft was initially carried out in the doors open configuration. The level of hydrocarbon vapour in the operations we were able to monitor did not exceed the stipulated threshold limit value (TLV) of 400 parts per million (ppm). A limited experiment was carried out in the doors closed configuration, here again it was found that the level of hydrocarbon vapour was well below the TLV of 400 ppm. Repeating the procedure for a refuelling/defuelling sequence also resulted in hydrocarbon values, though higher than the previous levels, lower than the TLV of 400 ppm. It is felt that refuelling even under maximal operating frequency would not present a significant occupational health hazard from hydrocarbon vapour to refuelling personnel. It is emphasised that the concentrations of hydrocarbon vapour were present only in the immediate vicinity of the refueller and fuel point.

### Ground Support Equipment

Ground support equipment produce two main pollutants, noise and exhaust emission.

(a) Noise This is common to all the ground service equipment in current use. The noise levels for each individual item could be hazardous to the unprotected ear and the noise levels from combinations of equipment could be hazardous to a degree which requires limitation of exposure duration even with current in-service ear protection equipment. The worst case noise level recorded was a 122 dB(A) which with an approximate attenuation of 28dB(A) for current in-service equipment permits an exposure duration of about one hour per day.

(b) Exhaust emission. These are from ground support equipment, some of which are petrol engined and some of which are diesel engined. The only ground support equipment which is turbine engined is the air starter.

The exhaust emissions of petrol and diesel engines include, carbon monoxide (CO), Oxides of nitrogen (NO and $NO_2$), Oxides of Sulphur ($SO_2$), unburnt hydrocarbons, particulates and, in the case of petrol engined equipment, lead. With non-leaded petrol the emission could contain manganese (Mn) when the proposed additive MMT* (Methyl cyclopentadienyl manganese tricarbonyl) is included.

* Data from animal studies indicate that there is no significant hazard from this substance. (Stara 1973)[1].

(1) The unburnt hydrocarbons and particulates. The unburnt hydrocarbons are a function of the efficiency of the engine. Normally after an initial burst at start-up hydrocarbon emission should be minimal at operating RPM.

The particulates comprise carbon, and metals including lead. Baker, et al, (1971)[2] have demonstrated a disturbing feature of these particulates particularly ferric oxide which can act as a carcinogen in association with benzo (a) pyrene. We have carried out air sampling for lead, and from this a reasonable estimate of the other particulates can be made. Our reason for looking at lead initially is because it has been shown that particulate matter from motor cars contains about 40% lead. (Crider 1971)[3]

(2) The oxides of nitrogen and sulphur. These were not detected in any significant amounts in the initial survey; also confirmed at the subsequent environmental profile.

(3) Carbon Monoxide. Carbon monoxide detected from ground equipment ranged from 10-30 ppm in the doors open state to over 300 ppm in 20 minutes with the door closed for 2 items of ground service equipment. From both petrol and diesel engines through start-up to operating RPM considerable quantities of CO can be expected.

## Aircraft Engines

Here again the main pollutants are noise and exhaust emission.

(a) Noise. The noise levels from the aircraft engines were about 124dB(A), this was inclusive of the ground support equipment. The duration of the noise is short lived, and as stated earlier limitation of exposure with protective equipment should ensure that the otological hazard is minimal.

(b) Exhaust emission. The exhaust emissions from turbine engines include the following:-

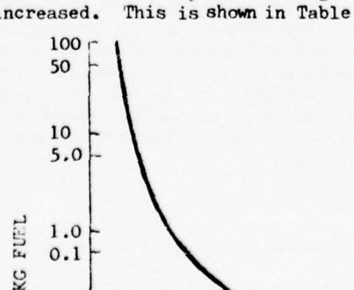
hydrocarbons

oxides of nitrogen

carbon monoxide

(a) Hydrocarbons. Sawyer et al (1973)[4] describing the factors controlling pollutant emissions from gas turbine engines showed that the hydrocarbon emission was mazimal at low power settings and diminished rapidly as the power was increased. This is shown in Table 1.

Table 1 - HYDROCARBON EMISSION

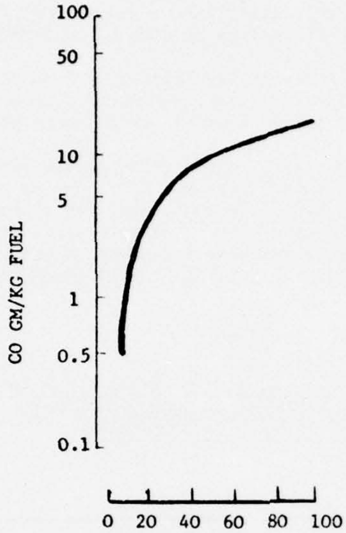


(After Sawyer et al 1973)

(2) Oxide of Nitrogen. Also based on the work of Sawyer et al (1973)[4] we see that in the case of oxides of nitrogen (NO) the output is minimal at low power settings and rises rapidly with increasing power, as shown in table 2.

TABLE 2

OXIDES OF NITROGEN EMISSION



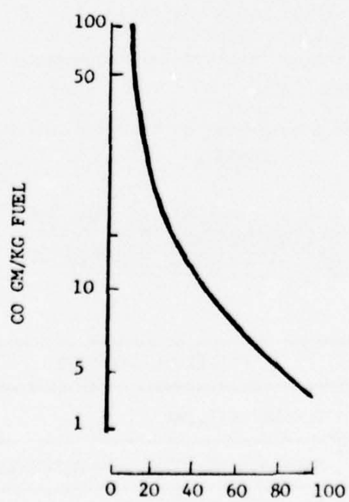

(After Sawyer et al 1973)

(3) Carbon Monoxide. This shows a similar output to that of hydrocarbon; at start-up the output is high and as the power is increased the output rapidly falls.

This is shown in Table 3.

TABLE 3

CARBON MONOXIDE EMISSION




POWER % (After Sawyer et al 1973)

To summarise therefore the pollutants of concern are:

Noise which we are able to contain.
Particulates which on initial assessment are of a low order and therefore can be discounted at this stage.
Oxides of nitrogen and hydrocarbons. This as shown in the tables for the aircraft engine shows an increase in the case of nitrogen and a decrease in the case of hydrocarbon with increasing power. These 2 pollutants and also the carbon monoxide from the aircraft engine (which tends to fall with increasing power) do not constitute a problem. This is because soon after start-up in the shelter the aircraft taxies out clearing the hangar of all pollutants by the exhaust flow through. However there is the question of carbon monoxide from ground service equipment which remains in the hangar during the pre-start-up procedures. It is therefore worth considering briefly the toxicology of carbon monoxide.

Carbon monoxide. We are dealing with levels ranging from 10-30 parts per million under optimum conditions to over 300 parts per million under "worst-case" conditions. The threshold limit value for carbon monoxide is 50 parts per million.

MacGregor (1973)[5] studied the maximum carboxyhaemoglobin (COHb) levels after an 8 hour time weighted average exposure to 50 and 35 ppm of carbon monoxide for smokers and non-smokers. The base line COHb level for a smoker is taken as 7.3% and that for a non-smoker is 1.4% (McIlwaine 1968)[6]. From table 4 it will be seen that for an 8 hour exposure to 50 ppm carbon monoxide the smoker maintains his base line depicted as "a" and the non-smoker attaining a level of 7.3% (MacGregor 1973).

TABLE 4

MAXIMUM CARBOXYHAEMOGLOBIN LEVELS AFTER AN 8-HOUR TIME-WEIGHTED AVERAGE EXPOSURE TO 50 OR 35 PPM CARBON MONOXIDE

| TIME WEIGHTED AVERAGE | SCHEDULE PPM X TIME HR | MAXIMUM % CARBOXYHAECOGLOBIN | |
|---|---|---|---|
| | | NON SMOKER | SMOKER |
| 50 | 50 x 8 | 7.31 | a |
| 50 | (75 x 4) (25 x 4) | 8.58 | 10.47 |
| 35 | (35 x 8) | 4.02 | a |
| 35 | (10 x 7) (200 x 1) | 8.48 | 12.5 |
| 35 | (10 x 6) (100 x 2) | 6.99 | 11.0 |
| *35 | (10 x 7) (200 x 1) | 12.9 | 14.1 |

V = 9.5 L/min Light activity
*V = 18.0 L/min Light work
a = maintains level of carboxyhaemoglobin from smoking

(MacGregor 1973)

The principle symptoms in relation to COHb % according to Lindgrem are shown in Table 5.

TABLE 5

APPROXIMATE RELATIONSHIP BETWEEN THE AMOUNT OF CARBOXYHAEMOGLOBIN IN THE BLOOD AND THE PRINCIPAL SYMPTOMS

| % COHb | PRINCIPAL SYMPTOMS |
|---|---|
| 7 | SLIGHT HEADACHE |
| 12 | MODERATE HEADACHE AND DIZZINESS |
| 25 | SEVERE HEADACHE AND DIZZINESS |
| 45 | NAUSEA VOMITING, COLLAPSE? |
| 60 | COMA |
| 95 | DEATH |

Lindgrem 1971

It may be argued smokers should have a slight headache all the time! However, at concentrations of 12% and above it may be assumed that all persons can be expected to have some symptoms. If we now look at exposure durations increasing progressively to 24 hours at 50 ppm CO based on Peterson et al (1970)[7] Table 6 shows that the rate of rise of COHb is rapid initially and less after about 6 hours exposure. The significance of this may be appreciated when we consider the half life of CO later.

TABLE 6

TWENTY-FOUR EXPOSURE TO 50 PPM OF CARBON MONOXIDE
CARBON MONOXIDE

| DURATION IN MINUTES | AVERAGE CO IN PPM | PERCENTAGE CARBOXY HAEMOGLOBIN | | | | | |
|---|---|---|---|---|---|---|---|
| | | S1 (A) | (E) | S2 (A) | (E) | S3 (A) | (E) |
| 0 | 0 | 0.65 | - | 1.5 | - | 3.9 | - |
| 60 | 51.74 | 1.80 | 1.86 | 2.6 | 2.58 | 4.6 | 4.62 |
| 180 | 49.93 | 3.80 | 3.64 | 4.4 | 4.17 | 5.7 | 5.66 |
| 360 | 50.00 | 4.90 | 5.50 | 5.55 | 5.83 | 4.8 | 6.75 |
| 480 | 49.32 | 5.50 | 6.25 | 6.1 | 6.48 | 7.2 | 7.15 |
| 720 | 49.48 | 6.50 | 7.29 | 6.6 | 7.42 | 7.9 | 7.77 |
| 930 | 49.39 | 7.20 | 7.76 | 7.5 | 8.04 | 8.2 | 8.04 |
| 1,320 | 49.21 | 8.10 | 8.14 | 8.6 | 8.17 | 8.7 | 8.27 |
| 1,440 | 49.04 | 7.60 | 8.20 | 8.0 | 8.22 | 8.2 | 8.29 |

(Peterson 1970)

The rate of CO uptake in light activities, based on the work of Forbes et al (1945)[8] as one would envisage in shelter operations (normally) is shown in Table 8. In the worst case conditions monitored at 300 ppm (0.03% CO) COHb levels of 15% after 2 hours and 25% after 4 hours can be expected. This is clearly undesirable.

TABLE 7

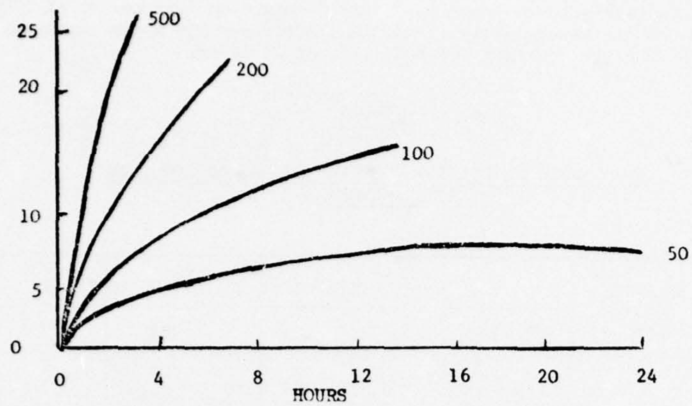
*LIGHT ACTIVITY PERCENT COHb IN BLOOD*

| PERCENT CO | 1 HOUR | 2 HOURS | 3 HOURS | 4 HOURS | 5 HOURS | 6 HOURS |
|---|---|---|---|---|---|---|
| 0.02 | 6.0 | 10.6 | 14.3 | 17.2 | 19.6 | 21 |
| 0.03 | 9.0 | 15.0 | 20.0 | 25.0 | 26.0 | - |
| 0.04 | 11.3 | 20.0 | 26.3 | 31.0 | - | - |
| 0.06 | 16.4 | - | - | - | - | - |
| 0.08 | 21.3 | - | - | - | - | - |
| 0.10 | 26.0 | - | - | - | - | - |

(Forbes 1945)

If we now look at the up take of various concentrations of carbon monoxide as a function of time, Table 8 from MacGregor (1973)[9] shows that at levels of CO below 100 ppm a state of equilibrium is attained at a level of COHb in 5-10% range, whilst with levels of CO above 100 ppm there is a rapid increase of COHb with time and little evidence of a state of equilibrium.

TABLE 8




UPTAKE OF CARBON MONOXIDE
AS A FUNCTION OF TIME (MacGregor 1973)

Finally, if the excretion of CO from the body is considered, Peterson (1970)[9] found it to be a half-life phenomenon. He showed in 38 separate experiments that the average half life was 320 minutes. This is consistent with the values seen earlier (Table 6) where we saw that the COHb levels increased rapidly till about 6 hours and then tended to level off. Another feature which Peterson demonstrated was that the half life of COHb in blood varied inversely with the partial pressure of oxygen in the respired air; a factor which might be of relevance in the treatment of persons exposed to high concentrations of CO. Peterson's (1970)[9] figures are shown in Table 9.

TABLE 9

| CO PPM | t MIN | t' MIN | MEAN COHb IN BLOOD % | |
|---|---|---|---|---|
| 507 | 114 | 10 | 23.00 | OXYGEN INHALATION AT NORMAL PRESSURE 760 mm Hg |
| | | 20 | 20.80 | |
| | | 30 | 19.55 | |
| | | 40 | 18.15 | |
| | | 55 | 15.85 | |
| | | 75 | 13.90 | |
| | | 95 | 12.80 | |
| | | 135 | 11.65 | |
| 473.3 | 140 | 0 | 19.4 | OXYGEN INHALATION AT HYPERBARIC PRESSURE (2,300 mm Hg) |
| | | 10 | 13.25 | |
| | | 20 | 10.0 | |
| | | 30 | 7.6 | |
| | | 40 | 5.85 | |
| | | 50 | 4.15 | |

(Peterson 1970)

I have attempted to outline in general the problems we have encountered in operating aircraft from shelters. In particular the problem of carbon monoxide exposure is complex and the formulation of an acceptable threshold limit value for operational occupational exposure is not simple. Back (1973) has quoted emergency exposure limits (EEL) and TLVs for US Air Force use for carbon monoxide as follows:

| | TLV | EEL 10 min | EEL 30 min | EEL 60 min |
|---|---|---|---|---|
| Carbon monoxide (ppm) | 50 | 1500 | 800 | 400 |

In an emergency situation these values must be deemed acceptable, however for continued exposure in situations where detriment to performance and efficiency cannot be accepted lower values must be considered. Based on the information available so far, and the data put forward our proposals are that for operational occupational exposure (in these circumstances) 50 ppm carbon monoxide be accepted as the TLV with a maximum permissible concentration in any given operational sequence of 75 ppm carbon monoxide.

Though the initial surveys have indicated that there is no significant occupational health hazard from other toxicological products, biological monitoring (for e.g. lead and benzene) should be carried out to assess if there is evidence of high absorption despite the low airborne concentrations recorded so far. These examinations should include:-

(1) Medical Inspection on commencement of employment.

(2) Baseline vitalograph recordings (forced expiratory volume and vital capacity).

(3) Baseline screening audiometry.

(4) Baseline estimation of carboxyhaemoglobin levels.

(5) In addition to these, regular monitoring of sample groups for the above parameters together with estimations of blood lead and urinary phenolic bodies where there is reason to suspect a high lead content in the fuel or where aviation fuel of the type containing a high benzene content is used.

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# DISCUSSION

**Dr Kenneth C.Back**

1. It is not likely that CoHb would increase in a smoker with 7% saturation. In 35 ppm the pressure gradient would be in the opposite direction i.e. the smoker would be adding CO to the air.

2. Levels of 20% CoHb saturation do not cause headache and drivers studied at Ohio State University Studies have shown no changes in performance at a high level.

3. We have done studies which show that 400 ppm CO inhaled continuously (24 hrs/day for 6 months) produced CoHb saturations of up to 30% with marked increase of haematocrit of approx 60-70. This is obviously due to increase in total Hb levels up to 25 gm/100 ml.

**Author's reply**

1. Dr Backs comments are accepted. In the case of the first comment which refers to my slide on the maximum carboxyhaemoglobin levels after an 8-hour time-weighted average exposure to 50 or 35 ppm carbon monoxide. This data is based on a theoretical examination of carbon monoxide kinetics with a comment on time weighted average exposures by MacGregor. <u>In a time weighted average</u> exposure to 35 ppm, whilst the pressure gradient at and below 35 ppm may theoretically be in the opposite direction, the pressure gradient will be reversed when the CO levels are above 35 ppm; which would account for the increase in CoHb in a smoker at time weighted average inhalation of 35 ppm CO (e.g. 35 = 10 x 7 + 200 x 1) or (10 x 6 + 100 x 2).

2. Levels of 20% may not cause headaches in some people and indeed the drivers studied in the Ohio State University survey may not have shown a decrement in performance. It would be difficult however, to generalise on these statements. In the type of operations we are considering, it would be quite wrong to consider CO in isolation and formulate preventive measures without taking account of the total environmental profile

3. Though such high concentrations are unlikely to be encountered for the durations stated, we will take account of this work in the long term supervision of personnel employed in aircraft shelter operations.

**Colonel C.Giannopoulos**

In the battery of tests, recommended for pre-employment and/or periodic medical examinations of personnel working in aircraft shelter operations, do you include liver function tests? (e.g. serum transaminase levels determinations).

**Author's reply**

It is not intended to include liver function tests as part of the baseline screening medical examination. In the pre-employment medical examination, personnel with a previous history of hepatic disfunction will however, be referred for full clinical evaluation before acceptance.

As a monitoring procedure liver function tests are not thought to be useful in assessing the exposure of personnel employed in these operations. In the case of benzene for example, the estimation of urinary phenol will give an early estimate of the absorption of benzene. It is emphasised that urinary phenol on its own is not conclusive of benzene absorption; recent work has shown that elevated urinary phenol levels which are unrelated to benzene exposure can be found following ingestion of common medications such as peptobismol and chloraseptic lozenges.

# CO DOSE METER FOR WORKING PLACES EXPOSED TO EXTREME PEAKS OF CO-CONTAMINATION.

G. Kleinhanß, M.D., Col., Chief of Defense Physiology Division in the Institute for Defense Medicine and Hygiene, Koblenz, FRG.

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## SUMMARY

For certain marginal conditions the product of carbon-monoxide (CO) - concentration (c) x time (t) of exposure $c \cdot t$ determines the amount of CO-load, which affects subjects working in several industrial and military working places. The determination of $c \cdot t$ is easy whenever c remains constant; if c varies, the following methods can be used,

1. Continuous integration of c over the time elapsed (IM)
2. Collection of aliquot quantities of gas samples during exposition and following multiplication of the mean concentration c with the time elapsed t (SM)
   Advantages and disadvantages of both last-mentioned methods are discussed.
   As consequence a
3. modified sampling method is introduced (MSM)

The MSM combines essential advantages of the IM and SM, especially accuracy, reliability in field tests and validity.

## FOREWORD

The average physiological effect of harmful environmental factors in general may be described to be subject to intensity and duration of exposure. Whenever duration of exposure can be regarded to be constant, for instance in an 8 hours'shift, maximum permissible intensities (MAC-values) are quite often defined as maximum loads in practical use. Maximum loads for working places with considerably unsteady intensities (peaks of concentration), however, can be only defined in an economically satisfying way, when both factors of influence, i.e. intensity and duration, are properly considered.
The effect (W) of carbon monoxide in the respirated air can be approximatively defined in the equation $W = c \cdot t$, considering certain marginal conditions, for instance degree of physical load, variability-range of concentration c and time of exposure t [1].
The amount of carboxy hemoglobin (HbCO) in blood has proved to be a dependable parameter to define the effect of CO produced upon man. For example 1o% of COHb in a normal adult are equivalent to a product W = 6000 ppm·min considering exposure durations between 2 minutes and 1 hour, changes in concentration between 1oo and 3000 ppm and a ventilated volume of 6o litres/minute [2,3].
Regarding the above mentioned marginal conditions a load of 6000 ppm · min within NATO Armed Forces are regarded to be the permissible maximum at this time [4].

## MILITARY IMPORTANCE

Peaks of CO-concentration up to 2000 ppm and even more can occur in the fighting compartments of MBTs due to gunsmoke of gun and secondary weapon. The civilian MAC-value (for instance in the industry) for CO concentrations, i.e. 5o ppm, will be surpassed more than a 4o-fold. On the other hand concentrations of that kind may be still within the range of human tolerance because of their short period of influence. A statement, making sense, whether this fact comes true or not, can only be achieved by evaluating CO-load from concentration and time of exposure.
In order to reduce CO-load in the fighting compartments of MBTs, if necessary, the following ways of realization are taken into closer account:

- Sucking off of the fumes at point of escape: i.e. at the breech blocks of gun and secondary weapon. Disadvantage: The necessary sucking device works against the pressurizing system which is in operation during missions under "buttoned up" - i.e. ABC-conditions. From this there is the possibility that either extraction of gunsmoke or ABC-pressurization is unsatisfactory.
- Supply of necessary fresh air to the crew using oxygenmasks which are fed by a central air cleaner. Disadvantage: Masks and connecting hoses reduce the necessary freedom of movement for the crew, especially for the loader.
- Equipment of the crew with CO-filter masks. Disadvantages, conditions: Presently available CO-filters from experience are only effective for short periods of operation. A sufficient amount of spare filters therefore must be always kept in stock.- The user must easily be able to find out when the absorbing capacity of his filter is expired.

As we have shown more closely in the case of MBTs, CO-protection always must be paid more or less dearly with more or less pronounced disadvantages in the operation of the actual system involved. These means, according to their extent, increase considerably the already sky rocketing production costs of modern weapon systems.
The choice of appropriate and economic protective measures presupposes a dependable estimation of possible CO-loads. We therefore tried to establish a method, to estimate CO-load ($W = c \cdot t$) as exactly as possible, and which also covers the demands of the field-test.

DETERMINATION OF W

1. Concentration c within single time intervals $t_1$ ... $t_n$ shall be constant. CO effect and its increase over the time of exposure can then be easily ascertained: $W = c_1 \cdot t_1 + c_2 \cdot t_2$ ..... $+ c_n \cdot t_n$. Especially in military working places c is very variable (peaks of concentration). In such cases CO-load can be computed continuously according to the product $c \cdot t$
2. from the formula $\int c \cdot dt$ (Integration-Method, IM).
   Accomplishment: c will be evaluated in sufficient velocity (for instance by an IR spectrometer) and electronically integrated over the time elapsed; $\int c \cdot dt$ recorded continuously.
   Disadvantages: The measuring range of the CO-analyser being used must be at least as wide as the maximum possible CO-concentration. From this follows that for instance on the bases of an over all systematic error of 2 % (in respect to maximal gauge), c incorporates an inaccuracy of ± 60 ppm, when peaks of concentration of 3000 ppm are taken into account. The measuring error is inevitably combined within an increasing inexactitude of the result of integration proportional to the time elapsed. For T = 60 for instance the inexactitude of the integral of concentration over the time means ± 3000 ppm·minute. As regards to the above mentioned limit of maximum permissible CO-load of 6000 ppm·min, a systematic measuring error of that amount reduces considerably the value of the results of measurings obtained in that way.
   During continuous integration of c over t errors in CO-measuring due to vibration may also occur. Especially in field tests mechanical influences on the vibration sensitive infra-red spectrometer often cannot be avoided. Transitory inaccuracies of the concentration gauge due to this phenomenon render an exact determination of $W = \int c \cdot dt$ impossible.
3. Sampling Method (SM)
   Collection of concentration samples into a reservoir over a total time elapsed T. After exposure total load dose may be estimated from the mean concentration $\bar{c}$, $W = \bar{c} \cdot T$.
   Disadvantages: No information about increase of W during single phases of the test, i.e. during single working periods, is possible. From the progress of W within a given time, however, important information about CO-sources and possible means of redress can be obtained. Also continuous safety control through continuous control of W during test is rendered impossible with this method.
   Therefore we have developed and tested a new and more precise method, which is more suitable for ergonomic field tests to determine the product of concentration and time.

PRINCIPLES [5] OF THE MODIFIED SAMPLING METHOD (MSM), FIG 1

A precision pump (PP) blows aliquot quantities of gas samples (for instance 1 litre/minute) of the gas under test into a Douglas bag (DB). The mean CO-concentration ($\bar{c}$) in the DB will be continuously measured in a closed circuit (CC) by a gas analyser (A). The pump (P) of A maintains the flow in the CC. At the beginning of the test CC contains a certain dead space (Vt) of CO-free air. If Vt is regarded to be zero ($\bar{c} = \bar{c}_0$) the following equation is rendered valid:

$$\bar{c}_0 \cdot T = \int_{t=0}^{t=T} c \cdot dt \qquad (I)$$

T = total time of test

In general Vt is always changing from test to test, being practically always greater than zero. The proper amount of it depends for instance from the accuracy being used to squeeze the residual air out of the Douglas bag. The following equation holds true for $V_t > 0$ according to (I):

$$\bar{c} \cdot (T + k) = \int_{t=0}^{t=T} c \cdot dt \qquad (II)$$

Derivation of Eq. I, II

$$(c_1 \cdot \dot{V} \cdot t_1) + (c_2 \cdot \dot{V} \cdot t_2) + \dots + (c_n \cdot \dot{V} \cdot t_n) / (T \cdot \dot{V}) + Vt =$$

$$[(c_1 \cdot t_1) + (c_2 \cdot t_2) + \dots + (c_n \cdot t_n)] / T + (Vt/\dot{V}) = \bar{c}; \quad \sum_{1}^{n} t_i = T$$

$$[\,] = \int_{t_0}^{t=T} c \cdot dt; \quad Vt/\dot{V} = k;$$

$\dot{V}$ = constant ventilated volume per time-unit of PP
Dimension of K is time!

The analogous voltage of A representing c is fed into the vertical registration-channel (Ry) of a x-y direct writing recorder, the horizontal channel of it is triggered by an electrical power source, increasing its voltage in linear correlation to the time elapsed. The registration paper is marked by a network of hyperbolic lines for constant W-values respectively, beginning with $W = c \cdot t = 2500$, 3.000, 4.000, ... 20.000 ppm (Fig 2).

Calibration of the system: (Example)

1. Ry Feeding-in of atmospheric air into A
   - Gauge indicates zero

   Feeding-in of air mixed with 500 ppm CO
   - Gauge indicates maximum
2. $R_x$ The deflection into the x-direction proportional to time, induced by the electrical power source must fit precisely to the line-network's dimensions in respect to polarity and amount, for instance 0,5 cm/min from left to right.

All connecting hose unions are connected according to Fig 1, the Douglas bag is empty up to $V_t$.

3. 5 minutes (PP on/off) filling in of a 500 ppm CO/air-mixture (CO/L). Afterwards atmospheric air will be administered to ascertain that the CO/air-mixture has reached the Douglas bag in total. Ventilator F will be switched on for approx. 3 minutes up to a constant CO concentration, indicated in the CO-analyser. (Gauge $<$ 500 ppm, for CO/L has been diluted by $V_t$.)
4. Adjust zero of Rx (manually and electronically) until pen is located on 2500 ppm·min-line. This procedure compensates the influence of $V_t$. (i.e. consideration of K in equation II).

Calibration is finished in that way. When measuring shall begin, P and time-voltage generator have to be started simultaneously. 2500 ppm min, already indicated after calibration, must be subtracted from the actually indicated value W, or the markings of the hyperbolic network must be recalibrated accordingly.

## TECHNICAL DETAILS

Gas analyser (A)

Infra-red absorption spectrometer. Measuring range 0-500 ppm. Accuracy ± 2 % over total measuring range, i.e. ± 10 ppm. Output of membrane pump for analysing chamber and CC approx. 30 litres/hour. Thermostatizing of the temperature sensitive measuring instrument has proved to be necessary especially during field tests. - Poor linearity in the concentration gauge can be observed incidentally even in brand new instruments. Control of linearity and adjustments if necessary are recommended (see below). Instrument should warm up for several hours before testing. Use of analysing chambers with $CO_2$-filters is recommended. Whenever vibration is expected to affect the analyser, the chamber's axis should be oriented vertically to the direction of maximal vibration as much as possible.
(Manufacturer: Hartmann und Braun, Frankfurt/M., FRG)

Precision pump (PP)

Two cylinder-piston-pump with a single motor. Piston displacement ratio discretely variable by interchangeable cog wheels (mixing pump). Output variability (load pump) optional accordingly between 4 and 87 litres/hour. In contrast to membrane pumps output is not or neglectably influenced by pressure changes, especially in the outlet. Constant output flow is indispensable for the measuring principle being used. Pressure rises up to 50 mm $H_2O$ in CC compared to static pressure at the beginning were observed with progressive filling up of DB. Output changes of PP occurred with changes of surrounding temperatures($>10^\circ$ C) due to changes in vicidity of the oil in the pump. Redress by use of viscostatic oils or temperature stabilization. PP is suitable for calibration and linearity control, being a mixing pump.
(Manufacturer: Fa. H. Wösthoff o.H.G., Bochum, FRG, Type 1 SA 18/3a)

Douglas bag (DB)

Bag made of proofed fabric, contents approx. 80 litres. Permeability for CO/L mixtures should be tested to eliminate possible gas losses or influences on gas concentration in CC during test. After installation of F in DB, service aperture in DB should be carefully sealed. Look for possible leakage! Wire and hosing connection of F and CC are led through original outlet (metal tube) of DB. Hosing connections of CC inside DB are approx. 80 cm long and furnished with several slots in the sidewalls, which ameliorate the mixing capacities of the system for F.
After each measurement a thorough flushing of at least 5 minutes' duration with atmospheric air is necessary in DB to eliminate any CO-residues. For flushing the blower of a commercial vacuum cleaner was used.
(Bag delivered by Hartmann und Braun, Frankfurt/Main, FRG)

x-y direct writing recorder (x-y)

Scale dimensions: Rx = 25 cm, Ry = 17 cm, accuracy 1 %; continuous setting of gain and zero-position of Rx, Ry by use of potentiometers.
(Manufacturer: Houston Omnigraphic Corp., Bellaire, Texas, USA, Type HR-195)

Ventilator (F)
Output capacity approx. 725 litres/minute, F is indispensable for sufficient stirring up of collected gas volume to get exact values of $\bar{c}$. Care should be taken to prevent the fan's rotating parts from damaging the inner surface of DB. F should be operated therefore only, when DB is already filled to a certain degree (for instance after 5 minutes of test gas aspiration).
(Manufacturer: Electrolux G.m.b.H., Hamburg, FRG)

Desiccators (D)
Tubes filled with sodium hydroxide and calcium oxide (NaOH+CaO) to avoid falsification of $\bar{c}$ values due to changing $H_2O$ and $CO_2$ contamination of the collected air. (Gross sensitivity of CO-analyser) Inner diameter of the tubes approx. 24 mm, length 80 mm.

## ADVANTAGES OF THE MODIFIED SAMPLING METHOD (MSM)

1. Comparison to Integration Method (IM)
The error in determination of c·t is considerably reduced when MSM is applied. In contrast to the determination of W = c·t through continuous integration a spectrometer (A) with a smaller measuring range can be used, when the modified sampling method (MSM) comes into use. (determination of $\bar{c}$). The errors in determining the products of concentration and time of both methods being compared are in the same ratio to the absolute errors in concentration respectively, as for example: ± 10 ppm in MSM : ± 60 ppm in IM = 1 : 6. The latter comes true under the condition that the relative exactitudes of each A being used (MSM, IM) do not differ (same grade) and that other possible sources of poor accuracy are balanced. In case of an error ratio of 1 : 6 and 60 minutes of a supposed duration of exposure, W can be evaluated for example with an accuracy of ± 600 ppm·min, when MSM is used; when IM is applied, an accuracy of ± 3600 ppm·min can be attained only (see above).

Transcient breakdowns, while concentrations are measured (field tests), produce only the losses of c·t-values for the periods of breakdown, when MSM is applied: whenever IM is used in a similar situation the whole result in general must be regarded useless.

2. Comparison to Sampling Method (SM)
In contrast to this method, in MSM the amount of W can be recorded continuously. Amount and increase of CO-load can be evaluated during different operating conditions in comparison to the increase of W over the time elapsed (t).
Applying also MSM each CO-concentration in the tested air at any chosen moment $c_i$ ($t = 0 \ldots i \ldots T$) can be evaluated from the graph of W, using the correlations $c_i' = \bar{c}_i\ (t_i + k)$; $c_i - \bar{c}_i = c_i'$ (Fig 3).
The fact that there is a constant maximal dead-time of approximately 10 seconds between the actual peak of gas concentration and its recording due to the dead-volume of the total hosing system must be additionally taken into account. This phase shift is also being observed in the IM, however.

## PROVING, PRACTICAL USE

The total error of W (Fw) in on-wire operation matched a fictitious spectrometer error (Fc) $<$ 3 %. Example: When measuring range of A is 0 to 500 ppm, $F_c$ = 3 %, a concentration error of ± 15 ppm and an $F_w$ of ± 15 t can be observed. For t = 10', 30', 60' – $F_w$ amounts ± 150, 450, 900 ppm min. In telemetry operation $F_w$ matched an $F_c$ of $\leq$ 3%.

After calibration the dependability of the measuring device can be tested by alternative input of atmospheric air (Zero-Gas) and a mixture of atmospheric air and CO of known concentration: When Zero-Gas is applied, the direct writing recorder must write parallelly to the hyperbolic network of lines on the recording paper; when the gas mixture is put into the measuring device according to time t and concentration c the exact value of the coordinates for W = c·t can be computed in advance. Especially the exact parallelity of the zero position of the direct writing recorder to the hyperbolic scale lines on the recording paper during zero-gas-testing has turned out to be a sensitive criterium for the linearity of the CO-analyser.
When W is determined in practice, parallelity of the value indicated to the scale lines on the recording paper indicates, that CO-load does not increase any longer. In such cases PP and the electronic time base (TB) should be switched off simultaneously until changed conditions make anew an increase of W probable. Transitory switching off of PP and TB increase the accuracy in determining W (error of W $\sim$ duration of test, see above).
Whenever data are transmitted by telemetry (for instance tests of CO-load in military vehicles under combat conditions) the test set up shown in Fig 4 has proved to be useful. Simultaneous switching on and off of PP in the vehicle and TB in the receiving station has been effectuated by impulses radioed directly by the telemetry system.

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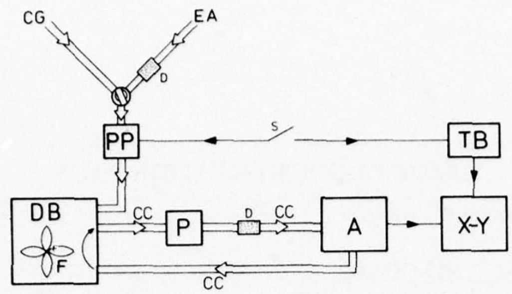


Fig. 1 Modified Sampling Method MSM, Block-diagram. CG Calibration Gas, EA Environmental Air, PP Precision Pump, DB Douglas Bag (with Ventilator F) CC Closed Circuit, TB Time Base, x-y-Recorder, s switch (to start simultaneously PP and TB), D Desiccator, ——— electrical wiring ═══ hosing connections.

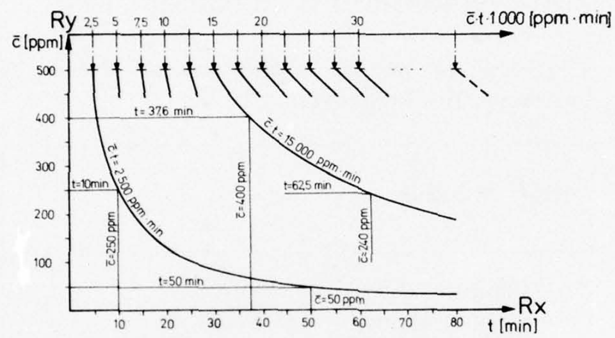


Fig. 2 Illustration of x-y network. Ordinate: Concentration $\bar{c}$, Abscissa: time-scale, Hyperbolic Scale-lines *of constant* $\bar{c} \cdot t$, *for ex.* 25oo and 15ooo ppm · min, further values $\bar{c} \cdot t$ not completely outlined.

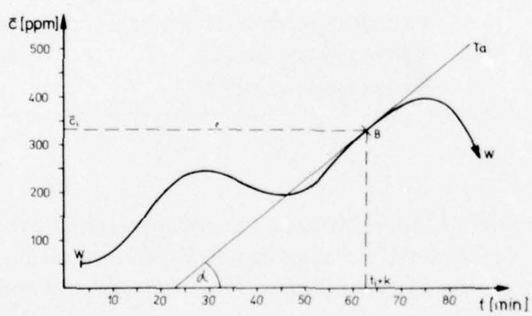


Fig. 3 Determination of momentary CO-Concentration by use of inclination of CO-load curve (W-curve); Ta tangent at B with angle $\alpha$. $\dot{\bar{c}}_i = \tan\alpha$ ; $c_i' = \dot{\bar{c}}_i \cdot (t_i + k)$; $c_i' + \bar{c}_i$ = CO-Concentration at point of time $t_i$.

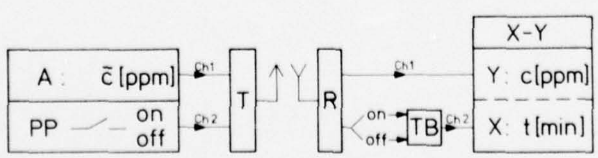


Fig. 4 Combination of MSM with telemetry data transmission; Ch 1, 2 → Telemetry Channels 1,2; T Transmitter; R Receiver, further Abbreviations see Fig. above. Principle of operation: Whenever PP will be switched on/off, TB will be started or stopped accordingly by telemetry signal.

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**14. Abstract**


This Proceedings contains twelve papers, arranged in groups dealing with their common aspects. The groups are sub-titled: (a) Medical, Psychiatric and Psychological Problems of Air Traffic Controllers and Radar Operators; (b) Monitoring, Measurement and Assessment of Potential Hazards Associated with Aircraft Operations; and (c) Industrial Hazards and their Control Associated with Aircraft and Missile Operations. Many of the current health hazards were identified and those that workers may be exposed to in the future were pinpointed. Recommendations were made as to their avoidance and control.

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